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Comparison of Domestic Fresh and Frozen and
Imported Frozen Goat Meat

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The School of Animal Sciences

by
Jeffrey Cole Denis Gregorie
B.S., Louisiana State University A&M, 2010
August 2016

This thesis is dedicated, first, in memory of my grandparents, Robert Leslie and Charlotte Faye Bell, who raised me and instilled in me the belief that I could accomplish anything I put my mind to as long as I was willing to do the work necessary to accomplish my goal. Secondly, I dedicate this thesis to my baby girl, Lisa Bell Gregorie, who has given me a renewed resolve to reach my full potential, because only then do I know that could I expect the same from her. Finally, I dedicate this paper to my Lord and Savior, for without him, none of this would be possible.

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ABSTRACT

The objective of this research was to determine differences in carcass evaluation, yield, and meat quality from representative fresh domestic (FSD), frozen domestic (FZD), and frozen imported Australian (FIA) goat carcass sides (n=30 from each source). The U.S. carcasses were split into sides and the right side frozen and stored for 6 weeks. Left sides were fabricated into standardized primal cuts. After frozen storage, right sides and FIA carcasses were thawed for 3 days at 4°C. Three experiments were conducted on the carcass traits and meat yields, quality differences in leg cut, and differences in loin and racks across freezing and packaging treatments. Domestic carcasses were heavier ($P<0.05$) with more ($P<0.05$) external fat, but carcass conformation and lean flank color were not different than imported Australian goat carcasses. Australian carcasses had less waste and higher trimmed primal loin, rack, leg, shank, and shoulder yields as % of carcass weight than domestic sides. Freezing and thawing changed the percentages of cuts, but FIA carcasses had higher ($P<0.05$) yields of lean trimmed primal cuts and FIA legs had higher ($P<0.05$) drip, cook losses, and water binding, but lower ($P<0.05$) color values than the FZD legs or FSD legs. With paired t-tests, FZD legs had higher ($P<0.05$) drip and cook losses and lower ($P<0.05$) color values than FSD legs. FZD and FIA chops had higher ($P<0.05$) drip and cook losses than FSD. Freezing lowered ($P<0.05$) color values of chops, however, packaging with 0.5% CO increased ($P<0.05$) a^* and chroma values of frozen meat over that of fresh goat meat before packaging. Vacuum packaging of goat chops increased ($P<0.05$) drip and chops in overwrap packaging had the lowest ($P<0.05$) color values. Packaging did not ($P>0.05$) affect Warner-Bratzler shear values. FSD chops had higher ($P<0.05$) shear force values than FZD, which were higher than FIA. Loin chops had greater ($P<0.05$) drip and cook losses

than rib chops. Rib chops were found to have higher ($P<0.05$) color values both pre and post package and lower ($P<0.05$) shear force values when compared to loin chops.

CHAPTER 1: INTRODUCTION

There has been increased demand and production of goat meat in the United States during the last 30 years (Gillespie, Nyaupane and McMillin, 2013). This demand increase is largely due to increases in immigration to the United States from major goat meat consuming countries. Unfortunately, domestic producers have not been able to fill the needs of the consumers for goat meat supplies. This has opened a path for alternative sources to fill the void.

Increased quantities of frozen goat meat are imported into the United States from Australia and New Zealand to meet the demand for goat meat, primarily from ethnic consumers. Imports of goat meat have increased over the past two decades with more than 19,630,658 kg imported into the United States in 2014, a number that increased nearly 50% since 2010. Imported goat meat, mostly frozen and from Australia, comprised more than 66% of the goat meat consumed in the United States in 2014 that can be accounted through inspected slaughter data (Pinkerton and McMillin, 2015). The shift from domestic production to a majority being imported meat in supplying goat meat to U.S. consumers is illustrated in Figure 1.

In an online survey of 2,000 goat meat consumers, type of cut accounted for 68% of the variation in respondent preferences, followed by product source, price and color that accounted for 15%, 14% and 3% of consumer preference, respectively. This implies that the type of cuts offered for sale is the most important attribute among goat meat consumers, with a demonstrated preference for cuts, chops and cubes (Harrison, 2013).

Most of the goat meat from Australia is in frozen form. Freezing meat prolongs the shelf life, but freezing and thawing processes affect the quality of the meat. Tenderness of meat as measured by peak shear force is generally thought to decrease with freezing and thawing

(Leygonie and Hoffman, 2012). The percentage of water loss within carcass and cuts is also expected to increase as a percentage within frozen carcasses (Lagerstedt et al., 2008).

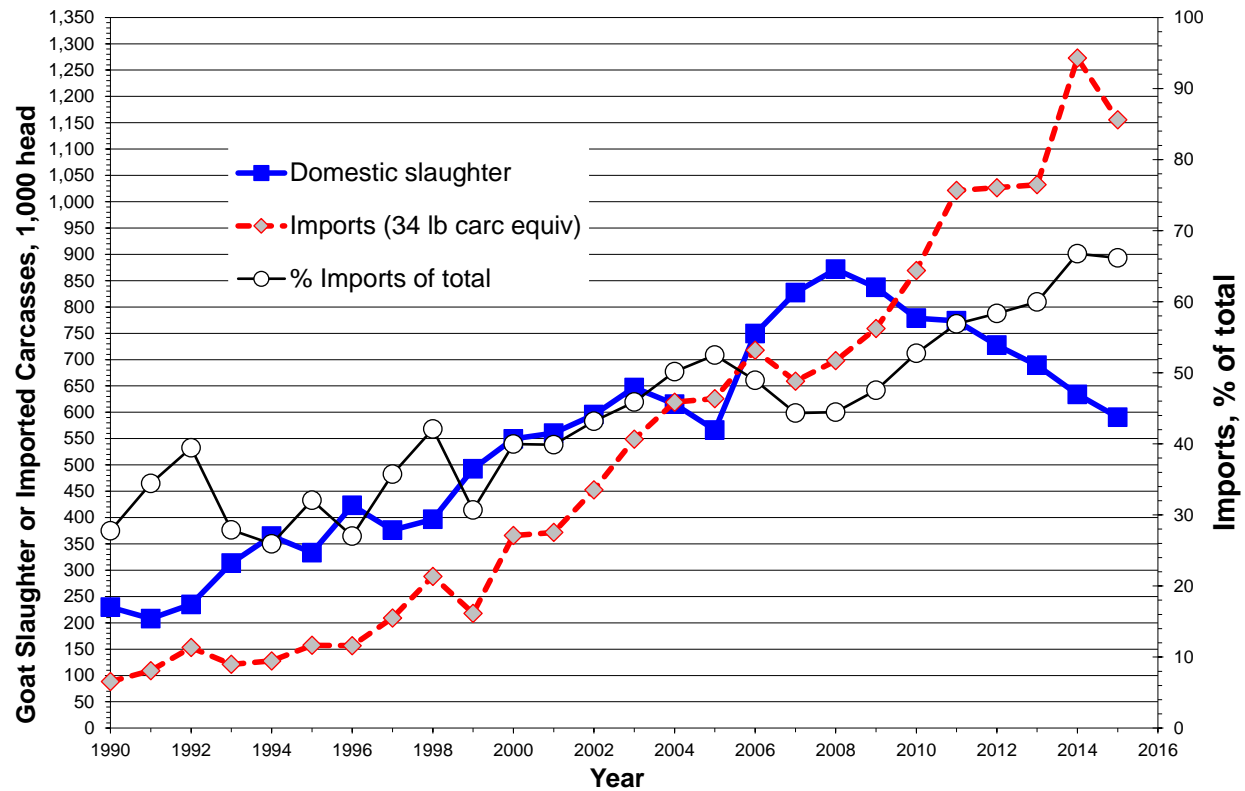


Figure 1. Annual domestic U.S. goat slaughter (head) and imports of goat meat (as 34-pound carcass equivalents) from 1996-2015. Percentage of imports as total number of goats from formal facilities on the right axis.

There is an abundance of research of freezing and thawing on quality effects in lamb; however, research in this area is lacking in goats. While sheep are the closest biological relative to goats in the domestic food chain, it has been stated that goat meat is unique and is not interchangeable with sheep or lamb meat. Thus, goat meat and goat meat products need to be marked and appreciated by the consumer for their own specific characteristics (Swan, Exguerra and Farouk, 1998). The only way to achieve this autonomy is by further research in goats, goat meat, and goat marketing.

The present study was designed to gain a comprehensive look at the quality differences from representative frozen Australian goat carcasses and from representative United States kid goats after both fresh and frozen storage. Goat eating consumers valued frozen domestic or frozen imported meat less than fresh domestic goat meat (Harrison, 2013). This research was designed to compare the carcasses, yields, and meat quality for these three types of goat meat available in the United States.

To achieve a comprehensive look at the differences among these groups, this study entailed three separate experiments. The experiments were conducted in two replications with fresh domestic goat sides and frozen domestic goat sides from American goats and imported frozen Australian goat carcasses. The experiments were evaluation of goat carcass traits and meat yields, differences in goat leg properties, and comparison of loin and rack chops in three different packaging treatments from fresh and frozen domestic and imported frozen goat carcasses.

There are confounding factors that occur by not being able to examine the fresh carcasses of the Australian goats and from not being able to control the freezing and storage of these sides. With that in mind, this study was designed with paired domestic fresh and frozen sides that could be compared to one another as well as to the Australian sides. This allowed for definite results between domestic fresh and frozen goat meat to be observed. Also, comparing the domestic fresh and frozen goat meat to frozen Australian goat meat would allow determining if Australian goat meat characteristics are more closely related in nature to those of frozen domestic or to fresh domestic goat meat. This would lead to testing the assumption that traits in the Australian meat would be due to freezing and not to production or uncontrollable factors.

CHAPTER 2: REVIEW OF LITERATURE

2.1 Properties of Meat

2.1.1 Components of Lean Meat

The structural unit of skeletal muscle tissue is known as a muscle fiber, myofibril, or muscle cell. Muscle fibers constitute 75-92% percent of total muscle volume with connective tissues, blood vessels, nerve fibers, and extracellular fluid comprising the rest. Water is the fluid medium of the body and also is associated with cellular structures, in particular, with colloid protein molecules (Aberle et al., 2012).

After the conversion from muscle to meat, the lean meat of muscle consists of contractile mechanisms consisting of myofibril proteins, myosin and actin, in the form of many fibrils, fibers and fiber bundles, each encased in a light tubing or netting of connective tissue. Within each bundle, myofibrils are surrounded by sarcoplasm (consisting of 75% water and 6% sarcoplasmic protein) and other substances including myoglobin, salts, vitamins, and some fat, sinews, nerves, blood vessels, etc. (Ranken, 2000).

2.1.2 Effects of Rigor Mortis

One of the most dramatic postmortem changes that occurs during the conversion of muscle to meat is stiffening of muscles after death, the phenomenon of rigor mortis (Latin for “stiffness of death”) (Aberle et al., 2012).

ATP complexed with Mg^{2+} is required for a muscle to be maintained in the relaxed state (Aberle et al., 2012). When glycogen is inadequate to generate adenosine tri-phosphate (ATP) to break the bonds between actin and myosin, myosin and actin can no longer be held apart and rigor mortis begins (Lawrie, 1992). During early postmortem phases, stores of creatinine phosphate are used for the re-phosphorylation of ADP (adenosine diphosphate) to ATP (Aberle

et al., 2012). Upon death of the animal, ATP in the muscle is split to ADP and AMP (adenosine monophosphate) (Ranken, 2000). As stores of glycogen are depleted, phosphorylation of ADP becomes insufficient to maintain the tissue in a relaxed state. As ATP becomes limited, actomyosin bridges begin to form. As cross-bridges form, muscles contract, shortening sarcomeres and increasing muscle tension. Stiffness observed in rigor mortis is due to formation of these permanent cross-bridges between actin and myosin filaments because there is no energy left for the breakage of actomyosin bonds (Aberle et al., 2012).

The stiffness caused by this process lasts until the resolution of rigor, where muscle stiffness decreases. This decrease in muscle stiffness is due to degradation of myofibrillar proteins, resulting in dissolution of Z disks and loss of ultrastructural integrity, as myosin and actin will remain bound (Aberle et al., 2012).

In chilled meat supplied for manufacturing, the process of rigor is normally completed and no problems arise, but if the rigor resolution sequence is interrupted by cutting, chilling, freezing or cooking, toughness may result. Freezing meat early in rigor or before rigor commences, and when ATP is still present, may lead to “thaw rigor”, which is a strong contraction with toughening when the meat is thawed (Ranken, 2000). In thaw rigor, contraction is caused by sudden release of calcium into the sarcoplasm from the sarcoplasmic reticulum and mitochondria and may cause a physical shortening of 80% of the original length of unrestrained muscles. The sudden release of calcium is due to storage sites within the cell being damaged in the freezing process (Aberle et al., 2012). This can be mitigated by long frozen storage or slow thawing as ATP will slowly dissipate in the frozen state, leaving no energy for contraction (Ranken, 2000).

2.1.3 Effects of pH

Post mortem changes take place at the death of the animal, changing muscle into meat. One of the most significant changes in the conversion of muscle to meat is the lowering of muscle pH due to the accumulation of lactic acid (Ranken, 2000; Aberle et al., 2012).

When normal metabolism and the supply of oxygen to the bloodstream cease, glycogen is converted into lactic acid. This process is known as glycolysis and will take place until glycogen is no longer available. The accumulation of lactic acid results in a pH fall normally from 7.2 to 5.5. (Lawrie, 1992; Ranken, 2000).

The pH is important from both the standpoint of ultimate pH and the rate of pH decline in the prerigor to postmortem period (Faustman, 1990). Different variables can affect the rate in which pH declines in muscle during postmortem glycolysis. Species that have a greater amount of white muscle fibers have a more rapid decline compared to species with a greater amount of slow twitch muscle fibers (Lawrie, 1992). Other factors, such as muscle location, may also contribute to the rate of decline. In general, low pH values favor the oxidation of myoglobin, and low pH accelerates the production of bound oxygen (Faustman, 1990).

Two abnormal cases of this process are known as PSE and DFD. PSE or pale, soft, and exudative meat may occur if the pH falls very rapidly because of nervous excitement at the time of slaughter, especially in stress-susceptible animals (Ranken, 2000). The term exudative refers to the excess surface moisture released by the myofibrillar proteins (Faustman, 1990). For PSE, animals must have high glycogen supplies pre slaughter which results in lower ultimate pH values. However, the main damage is due to this value being reached quickly while the carcass is still warm, resulting in the precipitation of soluble sarcoplasmic proteins, poor water binding and pale color. The second case is known as DFD or dark, firm and dry meat. This is due to the

glycogen supply being low in the live animal possibly due to starvation, exercise, or long-term stress. Little lactic acid is formed and the pH is ultimately higher, leading to darker color, closed texture and increased water binding, but poor microbiological quality. Both of these conditions can be mitigated by good harvest procedures (Lawrie, 1992; Zhu and Brewer, 1998; Ranken, 2000; Faustman, 1990).

With both these cases, it should be noted that the ultimate pH of meat is predominantly determined by the amount of glycogen present in the muscle tissue at the time of harvest. Ultimate pH values have been reported as high as 6.0 for Boer goats; however, this high ultimate pH could also be an indication of pre slaughter stress, as previously stated (Swan, Exguerra and Farouk, 1998).

2.1.4 Myoglobin

Myoglobin is the water-soluble heme protein primarily responsible for meat color. In the living cell, it serves both as an oxygen-storage and an oxygen-delivery function (Hunt and King, 2012; Faustman, 1990).

The heme prosthetic group of myoglobin is composed of an iron atom with six bonding points or coordination links, four of which are attached to nitrogen atoms. Iron is bound within a protoporphyrin ring to the four nitrogen atoms. The non-protein heme group is attached to the protein (the globin) at the fifth coordination site by a bond between the iron atom and a histidine (proximal) residue. The sixth site is available for binding a variety of ligands, usually water or oxygen (Faustman, 1990; Ranken, 2000).

The heme iron may exist in a reduced ferrous or oxidized ferric form (Faustman, 1990). The color of the pigment depends on at least three factors: the oxidation state of the iron atom (it may be reduced, Fe^{2+} , or oxidized, Fe^{3+}); the nature of the group at the sixth bonding point of

iron; and the state of the globin. The globin may be native, as in raw meat, or denatured, as in cooked meat (Ranken, 2000). The ligand present at the 6th coordination site and the valance state of iron determine the color of meat via four chemical forms of myoglobin in uncured meat, deoxymyoglobin (DMb), oxymyoglobin (OMb), carboxymyoglobin (COMb) and metmyoglobin (MMb); see Figure 2 (Hunt and King, 2012).

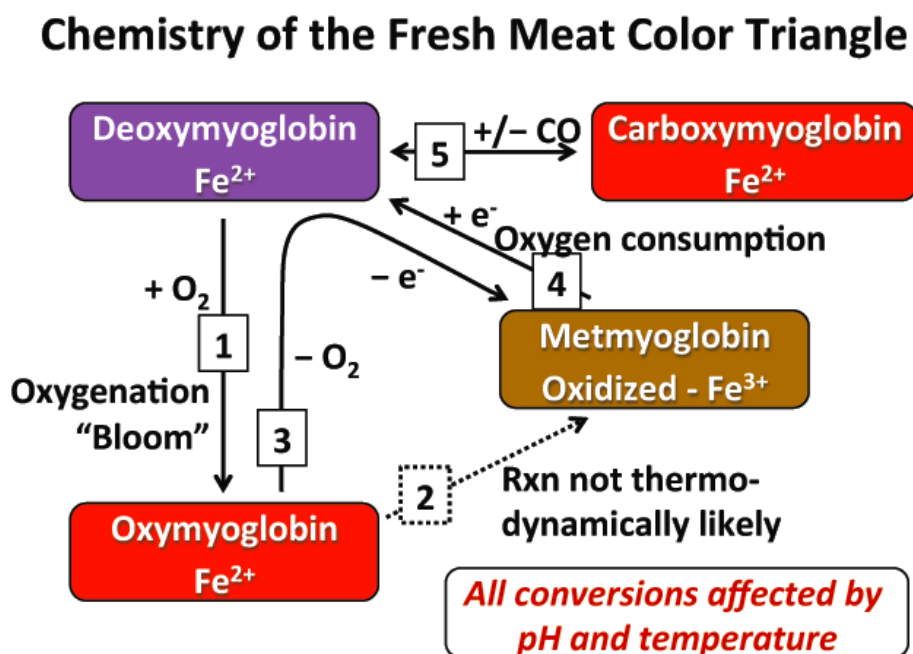


Figure 2. Schematic of the interconversions of myoglobin redox forms in fresh meat.

Ferrous heme iron, which lacks a sixth ligand, is called deoxymyoglobin. Meat in which deoxymyoglobin is the predominant pigment form will appear purplish-red in color. When oxygen occupies the sixth binding site of ferrous heme iron, oxymyoglobin results and is responsible for the desirable cherry-red appearance of fresh meat. These two reduced forms of myoglobin readily oxidize to the undesirable brownish-red metmyoglobin in which the heme iron is converted to the ferric state and water occupies the sixth coordination position. Metmyoglobin is incapable of binding oxygen, and thus physiologically inactive. Metmyoglobin

may be converted back to a physiologically active form by a process called reduction, facilitated by enzymes known as metmyoglobin reductases (Faustman, 1990). Under extreme conditions, the pigment may be decomposed; the heme portion becomes detached from the iron atom and green choleglobin and colorless bile pigments are formed (Ranken, 2000).

Reduced myoglobin, oxymyoglobin, and metmyoglobin are all present in fresh meat in equilibrium with one another. In the center of a piece of meat, there is no oxygen and the pigment is in the purple reduced myoglobin form (the same as vacuum-packed meats). At the surface of a piece of meat, there is a high oxygen supply and bright red oxymyoglobin is formed. Between these two zones is a region of low oxygen concentration, which favors oxidation of pigment to metmyoglobin. A layer of brown metmyoglobin therefore forms just below the surface of the meat (Ranken, 2000).

The relative proportions of the three pigments depend on conditions within the meat. Metmyoglobin cannot take up oxygen, but enzymes present in the fresh meat are capable of reducing metmyoglobin to reduced myoglobin, which can then take up oxygen to form red oxymyoglobin. With increased time postmortem, the substrates for these enzymes are gradually diminished; metmyoglobin can no longer be reduced and the brown metmyoglobin layer becomes wider until it finally becomes visible through a narrowing oxymyoglobin layer, and the meat appears brown (Ranken, 2000).

Carboxymyoglobin is another form of myoglobin that may be formed. Carboxymyoglobin in meat products is not new to the industry and has been allowed as a packaging aid in the United States since 2002 (Cornforth and Hunt, 2008). Carboxymyoglobin formation occurs when carbon monoxide attaches to the vacant 6th position of deoxymyoglobin, producing a stable bright-red color when the environment is devoid of oxygen. Atmospheres

containing oxygen (albeit concentration dependent) will result in the conversion of carboxymyoglobin to either oxymyoglobin or metmyoglobin (Cornforth, 1994).

Myoglobin concentration is variable with multiple factors including species, maturity, sex, and movement of the specific muscle, as concentrations are different for each muscle group (Ledward, 1992). The rate of myoglobin oxidation can also be greatly accelerated with increased temperature; therefore, the onset of discoloration in meat may be delayed with a low temperature stage (Faustman, 1990).

Hemoglobin, along with myoglobin, is another heme protein capable of imparting color in meat. Hemoglobin is a tetramer of myoglobin and is a component of red blood cells. However, in meat from properly exsanguinated carcasses, it is estimated that there is only an average of 0.3% residual blood in cuts, so hemoglobin is not a major contributor to color (Aberle et al., 2012).

2.1.5 Properties of Water in Meat

Meat juices play important roles in conveying overall impressions of palatability to consumers. They contain many components and assist in fragmenting and softening meat during chewing. The absence of juiciness severely limits meat acceptability.

The main source of juiciness detected by consumers is lipids and retained water. In combination with water retained, lipids form a broth, which is released during chewing. They may also stimulate the production of saliva and improve apparent juiciness (Aberle et al., 2012).

The water content of lean meat or muscle is approximately 75%, distributed as 45% attached to fibrils, 19% in sarcoplasm, and 11% in extracellular space and connective tissues. Of this water, 5% may be chemically bound to proteins, 24% of which is held by capillary forces and may be squeezed out under pressure; 45% is held firmly (Ranken, 2000).

During thawing, pressing, and cooking, the lost liquid comes from constitutive water and from the fat that melts during heating (Vieira et al., 2009). During cooking, melted fat apparently becomes translocated along bands of perimysium connective tissue. This uniform distribution of lipids throughout the muscle may act as a barrier to moisture loss during cooking. Subcutaneous fat also minimizes drying and moisture loss during dry heat roasting. In spite of influences of fat, the major contributor to the sensation of juiciness is water remaining in cooked product (Aberle et al., 2012).

Other factors may also affect the ability of a meat sample to retain water. Aging has been found to improve water-binding properties, causing aged meat to be juicier than un-aged meat (Schonfeldt et al., 1993; Aberle et al., 2012). Water losses both in drip and cooking losses are increased by freezing and thawing, the degree of which is largely dependent on the rate of freezing (Ranken, 2000).

Cooking losses in goats were higher on day 0 of display than any other time, likely due to the moisture losses over display time (Kannan, Kouakou and Gelaye, 2001). This was supported by research in beef that found overall water holding capacity is lowered with freezing (Lagerstedt et al., 2008).

Some of the common techniques to measure and quantify the moisture of a meat product are water holding capacity (WHC), the ability of the meat to retain the tissue water present within its structure, and water binding capacity (WBC), the ability of meat to bind added water. Drip is a measure of the water lost by holding a piece of meat under standard conditions. Drip from unprocessed fresh meat is usually quite small (0-3%). Cooking loss is water, fat or jelly which is lost from a piece of meat upon cooking. Finally, pressing loss is a procedure in which a standard weight of sample on a filter paper is pressed between two plates, and the area of the

paper wetted by liquid exuded from the sample is noted. Two examples are the Grau-Hamm press method and the Carver press method (Ranken, 2000).

2.1.6 Properties of Meat Color

The three sensory properties by which consumers judge meat quality are appearance, texture, and flavor. The appearance of the meat product is the primary factor that influences the purchase decision by consumers (Faustman, 1990) because the consumer puts emphasis on color as an indicator of meat quality (Kadim and Mahgoub, 2012a).

Muscle color is related to the concentration and form of myoglobin bound to iron and pH of the muscle (Kadim and Mahgoub, 2012a; Faustman, 1990) as previously stated. The most important contributors to meat color are the pigments that absorb certain wavelengths of light and reflect others (Aberle et al., 2012). Depending on the extent of blood loss from the animal, hemoglobin, the pigment in blood, may also play a factor in the color of meat (Ranken, 2000).

Acceptable fresh meat color is short-lived, and surface discoloration is inevitable and may be interpreted as an indication of unwholesomeness. Meat discoloration is easily defined as a divergence from the consumer defined ideal to something less desirable, for instance, cherry-red to brown. No single factor is responsible for meat discoloration. Meat surface discoloration largely depends on the rate of pigment oxidation into metmyoglobin, influenced by temperature, relative humidity, partial pressure of oxygen, light and lipid oxidation (Faustman, 1990).

The overall strategy for maximizing acceptable fresh meat color must involve delaying pigment oxidation and/or enhancing reduction of oxidized pigments. In general, greater pigment oxidation occurs in meat stored under light versus dark conditions, but because consumers generally like to be able to see the product they are viewing, this is an unavoidable effect in the displaying of meat (Faustman, 1990).

Factors such as species, breed, age, gender, muscle function and variation among and within muscles can affect meat color. The color of meat may depend on the nature of the illuminating light. The denaturing of myoglobin of meat also occurs faster at temperatures from 60°C and higher (Ranken, 2000). The color of frozen meat was found to vary with the rate of freezing. This was attributed to the change in light reflectance as caused by small ice crystals (Rasmussen and Olson, 1972). Red meats are darker, more brown/grey when frozen and tan when unfrozen (Ranken, 2000). Other extreme examples such as DFD, which has previously been discussed in relation to pH, can result in significant deviations to meat color from their expected values. DFD results in a tighter structure, which decreases the rate of oxygen diffusion and subsequent pigment oxygenation, and consequently decreases the amount of light reflected from the meat. Mitochondria also survive and function better in postmortem muscle tissue at elevated pH values, which is another contributor to darker meat (Faustman, 1990).

The brown or grey color associated with cooked meat is due to the denatured globin hemichrome that occurs at cooking temperatures causing the iron atom to be in the ferric state (Ranken, 2000).

In goat meat, desirable color values such as chroma decreased over display time in all types of goat cuts tested, however, some cuts differed in amount of discoloration from one another. Metmyoglobin formation increased in all goat cuts with increasing storage time, increasing significantly for each of the first 8 days, but with no increases thereafter. There was a significant negative correlation between percent of metmyoglobin and both a^* and chroma values. These relationships indicated that redness and color saturation decreased with increasing accumulation of metmyoglobin pigment in the meat. Color concentrations can depend on which

cut is being viewed, as shoulder cuts, for example, can have higher a^* and chroma values with lower hue angles than those of loin or leg cuts (Kannan, Kouakou and Gelaye, 2001).

2.1.7 Quantifying Color Measurements

Data on color stability of fresh meat gives an idea about possible consumer preferences based on the appearance of the product, but they do not necessarily indicate the safety, flavor, nutritional, or functional aspects of the product (Zhu and Brewer, 1998)

A color as detected by the eye is the result in a combination of several factors. Any specific color has three attributes known as hue, chroma and value. Hue describes the appearance which one normally thinks of as a color – yellow, green, blue, or red. In reality, it describes the wavelength of light radiation. Chroma (purity or saturation) describes the intensity of a fundamental color with respect to the amount of white light that is mixed with it. The value of a color is an indication of overall light reflectance (brightness) of the color (Aberle et al., 2012).

Accurate comparison of these properties of color in meat requires being able to quantify them. If a narrow beam of white light is passed through a glass prism, it is spit into a rainbow like band of color showing that white light is in fact a combination of all the colors of the spectrum. An object appears colored when some wavelengths of light are selectively absorbed. Fresh meat appears red because the surface absorbs all colors other than red wavelengths, which are reflected (Ranken, 2000).

These aspects of color are addressed directly in the color chart-based Munsell notation that specifies the elements of perceived color as value of lightness, (from black to white on a scale of 0 to 10), chroma (degree of departure from gray toward pure chromatic color), and hue (red, orange, yellow, green, etc.). In contrast, the instrumentally obtained coordinates from the commission Internationale de l'Eclairage, CIE (L^* , a^* , b^*) provide information on lightness

directly (McGuire, 1992). The development of the CIE $L^*a^*b^*$ color space allowed color to be expressed in a three dimensional space (Figure 3, (Hunt and King, 2012)).

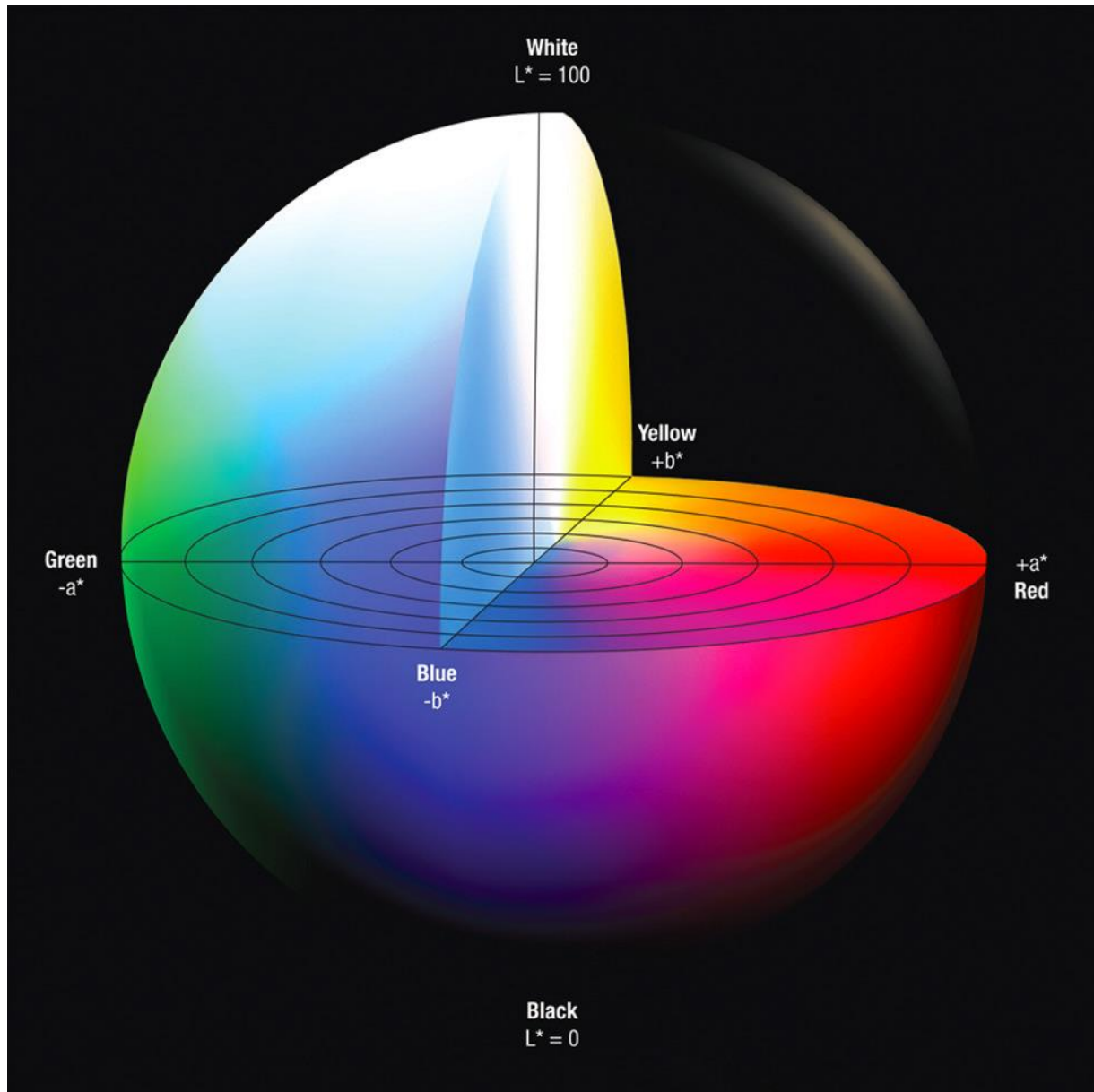


Figure 3. Representation of color solid for CIE $L^*a^*b^*$ color space.

Over 60% of researchers use Minolta colorimeters to instrumentally measure the values of color (Tapp, Yancey and Apple, 2011). Minolta colorimeters can give three values CIE L^* (0=black; 100=white), a^* (-60=green; +60=red), b^* (-60 =blue; +60=yellow). Many researchers

publish CIELAB (L^* , a^* , b^*) values, and while this gives a direct indication of lightness, the a^* and b^* values are merely coordinates and do not indicate the color differences or color saturation without further computation (McGuire, 1992). The coordinate points of a Minolta or Hunter colorimeter pinpoint the measured color in a three-dimensional color space. However, without further manipulation, this information does not provide an indication of hue and chroma (McGuire, 1992). From a^* and b^* , chroma is calculated as $(a^{*2} + b^{*2})^{1/2}$ and hue angle is calculated as $\arctan(b^*/a^*)$ (McGuire, 1992).

Pertinent information that is necessary to replicate and accurately interpret instrumental color results should include instrument type, illuminant type, aperture size, observation angle, number of readings taken per sample, and bloom time (Tapp, Yancey and Apple, 2011).

2.1.8 Cooking

The main function of cooking is to heat, treat and kill vegetative pathogens and make a product safe to consume (Varnam and Sutherland, 1995). Cooking is a process in which thermal treatment causes chemical, physical, and microbial changes to occur in food, finally leading to a palatable product (Ranken, 2000).

Many different methods of cooking can be used to ensure the safety of the product. Desired sensory qualities of the end product are the main factor in selecting a cooking method. Cooking methods may include hot air, steam, hot water, hot fat or oil radiant, dielectric heating, and extrusion cooking (Varnam and Sutherland, 1995).

At the start of cooking, meat has a flaccid feel. During the cooking process, the most obvious changes are the shrinkage in the muscle volume, with consequent loss of fluid, and the development of a rigidity that is absent with raw meat (Vieira et al., 2009). The firming of meat during cooking occurs as sarcoplasmic proteins are progressively precipitated from about 40°C,

thus meat becomes paler because of increased light scattering. The majority of the precipitation occurs above 60°C and is complete by about 70°C. Contractile proteins myosin and actin are denatured at about 65-70°C. When cooking to 65°C, the collagen and elastin shrink, increasing rigidity and toughness. Cooking over 80°C, the collagen begins to hydrolyze to gelatin (Ranken 2000). The residual strength of fibers binding the muscle together contribute to toughness of meat in addition to tension generated by the thermal shrinkage of perimysium collagen. Tensile properties of cooked meat along the fiber axis are about ten times greater than the force required to separate the bundles transversely (Vieira et al., 2009).

Other notable changes that take place during cooking are water loss, fat loss, and flavor changes (Ranken, 2000; Aberle et al., 2012).

2.1.9 Tenderness

Tenderness is the most important quality attribute of whole meat (Oreskovich et al., 1988). Texture is probably most important in determining the tenderness and eating quality of cooked meat, and the extent of change varies considerably from muscle to muscle (Vieira et al., 2009).

Toughening due to rigor mortis is caused by the formation of actomyosin bonds between myosin and actin bonds that in postmortem muscle become irreversible when ATP is depleted and are known as rigor bonds (Huff-Lonergan and Lonergan, 2005). The toughening effects caused by this process can be somewhat negated by the aging process (Olsson, Hertzman and Tornberg, 1994). The increase in tenderness associated with post-mortem aging of meat has been attributed to endogenous enzymes in muscle, a loss of tensile strength of the myofibrillar component of the muscle cell, and to shortening of muscle fibers during slow versus rapid phase of rigor mortis

(Smith, Culp and Carpenter, 1978). Other differences can be due to sex, breed, age, species and muscle (Lawrie, 1992; Aberle et al., 2012).

Tenderness is largely related to connective tissues that are formed mainly from fibers of collagen and small amounts of elastin. In young animals, the connective tissue is partially crosslinked and flexible, but with increased age, the degree of crosslinking increases, flexibility decreases and toughness increases (Ranken, 2000). Heat may cause both tenderizing and toughening of meat. In general, those heat-induced changes in proteins that result in coagulation and hardening reduce tenderness. Conversely, those changes that result in greater solubilization increase tenderness (Aberle et al., 2012). Improvement to tenderness of meat can be made through aging, mechanical, and enzymatic methods (Aberle et al., 2012). Peak force values in beef steaks have also shown a decline with freezing treatment and freezing time when compared to fresh meat; however, the sensory panel found fresh meat to be more tender and juicy than frozen meat (Lagerstedt et al., 2008; Shanks, Wulf and Maddock, 2002).

Tenderness can be a very subjective measurement; to estimate it objectively, mechanical shear force is commonly used. Shear force required to break tissue is a convenient, objective measurement of texture and, in general, correlates well with taste panel assessments of that parameter (Vieira et al., 2009). Warner-Bratzler shear force (WBSF) has been shown to accurately predict the meat tenderness rating of a consumer (Shackelfor et al., 1991; Warren and Kastner, 1992).

Some of the research done in goats, as it relates to tenderness, has found that goat carcasses are typically small, with little to no fat cover, and therefore carcass temperature can decrease rapidly during postmortem chilling. This rapid decline in carcass temperature may result in cold shortening and result in tougher meat (Kannan et al., 2006). Reducing stress prior

to slaughter has shown to result in more tender goat meat (Kadim and Mahgoub, 2012a). Aging goat carcasses for more than six days can result in increased tenderness (Kadim et al., 2003).

2.2 Overview of Frozen Meat

The overall freezing process applied to meats consist of three processes 1. The actual freezing operation, where most of the water in the food is converted into ice resulting in a hard solid material; 2. Frozen storage; 3. Thawing, where the frozen food is more or less transformed back into its original state. Prefreezing treatments (such as chilling), if any, should also be viewed as an integral part of the freezing process since they have the potential to influence product quality (Hanenian and Mittal, 2004; Fennema, 1966).

2.2.1 Chilling

Chilling can be defined as cooling material to temperatures just above the freezing point. The rate of oxidation of the pigment to metmyoglobin increases with increasing temperature, therefore red color is more stable at lower temperatures. At lower temperatures, the solubility of oxygen is greater and oxygen-consuming reactions are slowed down so therefore there is greater penetration of oxygen into the meat and the meat is redder than at higher temperatures (Ranken, 2000).

2.2.2 Freezing

The advantages of freezing meat rather than distributing it chilled are increased storage time and a greater flexibility in inventory for retailers (Wheeler et al., 1990). This is achieved through maintaining quality for longer periods than would be possible at higher temperatures (Ranken, 2000).

At the most basic level, freezing can be defined as the converting of unfrozen material into frozen material (Ranken, 2000). The commonly used types of freezing methods are

classified into three groups: 1. Blast freezing – freezing meat in a blast of cold air, 2. Plate Freezing - freezing by indirect contact with a refrigerant, 3. Immersion - freezing by direct immersion in a refrigerating medium (Tressler et al., 1968).

The main focus of this study is on blast freezing. In blast freezing systems, the products to be frozen are spaced to allow for maximal air flow around the product, by either hanging or being placed on metal trays/racks. The product may be either in loose form or in packages, and cold air is blown over the foods by large fans for quicker heat removal (Rasmussen and Olson, 1972).

The quality of frozen meat depends on the specific procedures used to freeze, store, and thaw the meat and the freezing rate can affect the quality of meat through the structural changes that occur during freezing because of the formation of ice crystals (Smith et al., 1968).

2.2.3 Freezing Rate

Freezing rate of a food mass is the ratio between the minimum distances from the surface to the thermal center (slowest cooling point) and the time required for the thermal center to reach a temperature of 10°C lower than the temperature of initial ice formation at the thermal center once the surface attains a temperature of 0°C (IIR, 1972).

A variety of terms may be used to describe a fast freezing rate: sharp, slow, rapid, quick, and ultra-rapid (Fennema and Powrie, 1964). It has been considered for many years that foods that are quick-frozen yield optimum quality. Quick frozen foods generally exhibit minimal textural damage, release less thaw exudate, and undergo less chemical deterioration than those frozen at low rates (Fennema, 1966; Fennema and Powrie, 1964). In rapid freezing, many small crystals are formed simultaneously inside and outside the cells and distributed uniformly

throughout the product; water bound to myofibrils is the last to freeze (Ranken, 2000; Fennema, 1966).

Slow freezing of foods generally results in the production of large ice crystals located exclusively in extracellular space that then grow as liquid is attracted to them. The result is large ice crystals outside the cell and some dehydration of the cell contents (Ranken, 2000; Fennema, 1966). Slow freezing is characterized by extensive dislocation of water and consequently, the cells have a shrunken appearance in the frozen state.

Drip loss from meat cuts upon thawing has been related to freezing rate when the surface area to volume ratios of the cuts were large. The free water has to move to the surface before it can drip from the meat, hence, the greater the surface area per unit volume, the less distance the water needs to travel (Hanenian and Mittal, 2004).

2.2.4 Frozen Storage

Frozen storage, as conducted on a commercial basis, is considered to be the most significant contributing factor to food damage in the entire freezing process. Foods in frozen storage undergo a gradual and significant decline in quality with time (Wheeler et al., 1990; Love, 1966; Shanks, Wulf and Maddock, 2002). Fluctuating temperatures in frozen material can cause the ice crystals to grow; the smallest ice crystals are the first to melt and upon refreezing, combine with larger ice crystals (Ranken, 2000).

Frozen storage time can cause an increase in muscle pH due to microorganisms and endogenous enzymes that degrade meat proteins and produce ammonia, organic sulfides, and amines (Devine et al., 1993; Muela et al., 2010). As frozen storage length increases, a decreasing trend can be observed in regards to L^* , a^* , b^* , and chroma values together with an increase in

hue angle. The differences are made more significant with added storage time (Vieira et al., 2009).

Even when fast rates of freezing would result in the optimum quality retention of foods, the effect can easily be offset by improper frozen storage or thawing. Some of the small ice crystals present in the food tissue as a result of fast freezing may recrystallize and enlarge due to metamorphic process, becoming more typical of those produced by slower rates of freezing (Hanenian and Mittal, 2004).

There is a possibility of freezer burn taking place in foods during frozen storage. This phenomenon is attributed to the sublimation of ice from the product surface, but this can be avoided by packaging the product in a material of low permeability to water vapor (Fennema, 1966). Meat with severe freezer burn is dry and tasteless, or if oxidative rancidity has developed, it may be viewed as bitter in flavor (Aberle et al., 2012).

2.2.5 Thawing

Thawing is also considered to be a more significant cause of quality damage than freezing (Hanenian and Mittal, 2004). When meat thaws, ice crystals can cause physical damage to the microstructures in meat. Thawing plays a major role in the processing of frozen meat because the amount of exudates generated in the thawing process is one of the measures of the quality of frozen meat (Anon and Calvelo, 1980).

Thermal conductivity of water is much smaller than that of ice; therefore, thawing is a slower process than freezing because heat has to pass through an increasing thickness of water instead of increasing thickness of ice. This leads to increased risk of microbial growth, as compared to freezing, because the surface of the meat is at a higher temperature and there are free water and nutrients for microbes on the surface of the meat (Ranken, 2000).

Proper precautions must be exercised during meat thawing to prevent microbial spoilage. Such precautions would imply the necessity of reduced thawing times as well as having a relatively cool thawing medium. A sufficient number of microorganisms invariably survive the freezing process and the frozen storage conditions, after which they can multiply and promote spoilage both during and after thawing. In general, thawing at temperatures ranging from room temperature to 49°C is considered to be detrimental in inducing surface spoilage prior to the completion of thawing (Fennema and Powrie, 1964; Fennema, 1966).

It should be noted that the color of thawed frozen meat is less stable than that of fresh meat, and any meat that has discolored during frozen storage will remain brown after thawing (Ranken, 2000).

One commonly used practice of thawing that has its own limitations is microwaving. Most foods exhibit a rather high degree of heterogeneity during thawing due to a simultaneous existence of frozen and unfrozen phases. Consequently, these distinct phases heat at quite different rates when subjected to a dielectric field, usually resulting in localized overheating prior to complete thawing (Fennema and Powrie, 1964).

2.2.6 Effects of Freezing on Meat Quality

It is thought that freezing reduces the meat quality and that consumers prefer meat that has not been frozen (Lagerstedt et al., 2008).

Most physical and chemical changes occurring in foods during freezing are caused either directly or indirectly from water to ice formation (Hananian and Mittal, 2004). The following factors were considered to be involved in food damage during the freezing operation: 1. Damage pertaining to the size and location of ice crystals within the food; 2. Mechanical damage caused by volume changes in the food structure; 3. Chemical damage resulting from the concentration of

non-aqueous constituents (Fennema and Powrie, 1964; Hanenian and Mittal, 2004; Sanz et al., 1999).

Rapid freezing results in the formation of small ice crystals which cause much light scattering, giving the meat a pale, opaque appearance. Slow-frozen meat contains large ice crystals, which scatter less light, so that the meat has a dark, translucent appearance. These color changes disappear on thawing (Ranken, 2000). Neither freezing method nor frozen storage time had a significant effect on lightness (L^*), but there were significant differences between fresh and frozen treatments. This suggests L^* was affected by the freezing and thawing process (Muela et al., 2010).

Meat has a more desirable frozen color if allowed to “bloom” in air before freezing. Metmyoglobin formation is maximal at about -12°C due to only a portion of the water being frozen, and discoloration is greatly increased by light. It is therefore recommended that the best storage conditions to preserve color are below -18°C and in the dark. Frozen and thawed beef was lighter in color than fast frozen meat because of differences in thaw drip, which may have resulted in greater light reflection and lighter color in the samples that were slowly frozen and thawed (Farouk, Wieliczko and Merts, 2003).

Food systems undergo non-uniform changes in volume during freezing as a result of the expansion of water into ice during the contraction of most of the other constituents. Consequently, there will be localized areas of expansion, with a likelihood of local stresses and mechanical damage (Fennema, 1966). When meat is frozen, the cell membranes are damaged, which results in a lower water holding capacity and a higher cooking loss and, consequently, a risk of less juicy meat (Wheeler et al., 1990).

As previously discussed, freezer burn can also be a detriment of freezing. Freezer burn occurs when ice sublimates from unprotected areas of the meat leading to desiccation, denaturation of proteins and oxidation of the pigments. This is in part exacerbated because moisture in freezers is drawn towards cooling coils. To prevent this, meat should be wrapped in moisture impermeable film (Ranken, 2000).

2.3 Packaging Overview

Fresh meat packages must provide protection from product contamination and deterioration, product visibility, and space for label information (Aberle et al., 2012). Raw or chilled meat will usually be displayed at retail in 1 of 3 packaging types: overwrapped, vacuum, or modified atmosphere (MAP) (Cole, 1986). Traditional meat packaging, such as overwrapping, uses atmospheric oxygen permeable moisture impermeable film materials to cause bloomed meat with oxymyoglobin pigment forms. Low oxygen packaging may be vacuum packaging or MAP with low O₂. MAP and vacuum packaging may also incorporate other gases to create a controlled atmosphere which can overcome some of the aforementioned color issues (McMillin et al., 1999).

2.3.1 Oxygen-permeable Film Overwrapping

Polyvinylchloride (PVC) film overwrapping has historically been the most widely used packaging of fresh meat, with PVDC (polyvinylidene chloride) films or copolymers of PVC and PVDC more recently available. One advantage of oxygen permeable PVC is maintenance of the bright red oxymyoglobin color, which depends on an adequate supply of oxygen. Packaging films must, therefore, have high oxygen permeability with five liters of oxygen per m² per day required. Coated cellulose films and low-density polyethylenes (LDPE) have high oxygen permeability, but low water permeability and are satisfactory (Ranken, 2000). Another advantage

of PVC packaging is that both the film and related equipment are relatively inexpensive and easy to use, allowing widespread use of this method in retail stores (Cornforth and Hunt, 2008).

Most fresh meat sold in self-service stores is packaged on rigid plastic trays with a film, such as PVC, as an overwrap. Trays provide strength to the package. Properties of overwrap are especially important because they regulate the gaseous environment in the package. To minimize moisture loss, the overwrap should have a low water vapor transmission rate. Fresh meat overwraps are designed to provide an abundant amount of oxygen at the meat surface so that there is abundant oxygen for oxymyoglobin, the bright red pigment. With good sanitation, meat may be maintained 5-7 days (Aberle et al., 2012). When surface browning due to metmyoglobin exceeds 40%, retail meats typically are discounted or discarded (Greene, Hsin and Zipser, 1971).

2.3.2 Vacuum Packaging

Most of the problems encountered with tray and overwrapping packaging of fresh meat may be overcome with vacuum packaging. Composition polymer films known as laminates, which have low water vapor and oxygen transmission rates, are used for vacuum packaging. Low pH and absence of oxygen inhibit further bacterial growth and significantly extend the shelf life of vacuum packaged meat up to 3 weeks (Aberle et al., 2012).

However, consumer objections to the color of such packages have inhibited wide spread use of vacuum packaging because with no O₂ present, myoglobin will be in the purple, reduced form. The meat will retain this color for long periods in vacuum packs. Bacterial growth is restricted under vacuum conditions, which is another advantage. The purple color is not generally acceptable to retail consumers, but the bright red color of oxymyoglobin is restored soon after the pack is opened (Ranken, 2000).

2.3.3 Modified Atmosphere Packaging

The meat industry has recognized the importance of color stability of fresh meat marketability and the recent revolution in modified atmosphere packaging (MAP) has resulted from the need for extended shelf-life (Faustman, 1990). Not only can these packages extend shelf life, but they can be shipped to stores in a “case-ready” format for retail display, allowing supermarkets to offer retail fresh meat products at a lower cost (Cornforth, 1994).

The basis of MAP is essentially the removal and/or replacement of the atmosphere surrounding the product before sealing in vapor-barrier material (McMillin, 2008). Efforts are made to control the gaseous atmosphere in meat packages to achieve bright red color and microbial control through the use of MAP (Aberle et al., 2012). In high oxygen MAP, meat packed in gas impermeable packs may contain a high concentration of oxygen above 40%. Color quality can be maintained for up to 14 days in the right conditions (MacDougall and Taylor, 1975). Carbon dioxide gas may be added to suppress bacterial growth (Faustman, 1990).

Commonly, an 80% oxygen and 20% carbon dioxide (CO₂) mixture is used, as the CO₂ has a microbial controlling effect and the oxygen allows the formation of oxymyoglobin in fresh meat, which imparts the desirable red color (Ranken, 2000; Aberle et al., 2012). A variant, in which a pack is made initially with high portions of carbon dioxide in the headspace atmosphere for the preservative effect of the CO₂, can be used (Ranken, 2000). Oxygen concentrations higher than 21% in modified atmosphere packaging using combinations of O₂, CO₂, and N₂ will increase the proportion of oxymyoglobin pigments (McMillin et al., 1999). However, even though carbon dioxide helps control microbial growth, oxygen reduces the beneficial effects, making high oxygen MAP only slightly more beneficial than that of oxygen permeable films (Faustman, 1990).

Nitrogen (N₂) has been used in place of oxygen, however, this led to meat having the purplish color associated with vacuum packaged cuts (Aberle et al., 2012). With fresh meat to be held in bulk, it is desirable to keep the oxygen concentration as low as possible, and preferably to eliminate it altogether, so a combination of N₂ and CO₂ is commonly used (Ranken, 2000). When compared with N₂ and CO₂ mixtures, meat packaged with O₂ has limited distribution and display life because color and lipid oxidation occurs within a relatively short time (Cole, 1986). Conversely, O₂ concentrations higher than 21% in modified atmosphere packaging using combinations of O₂, CO₂, and N₂ will increase the proportion of oxymyoglobin pigments (McMillin et al., 1999).

The most recent meat packaging technology is anaerobic MAP with low levels (0.4%) of carbon monoxide (CO), 20 to 30% CO₂, and the remainder N₂ (CO-MAP). Since 2002, CO has been permitted as a MAP gas for use during distribution in the United States. In 2004, CO was further permitted at low levels as a MAP gas in retail fresh meat packaging in the United States (Cornforth and Hunt, 2008).

Packaging in CO-MAP offers several advantages over aerobic packaging with PVC or high-oxygen MAP. A desirable red color stability associated with lower spoilage levels for as long as 28 days, better flavor acceptability due to no oxidized flavors, no bone darkening relative to high-oxygen, no premature browning during cooking, and increased tenderness due to less protein oxidation in anaerobic environment and also due to longer shelf life, allowing continuous action of endogenous tenderizing enzymes can be expected (Cornforth and Hunt, 2008).

A note on MAP gases that should be considered is that from a regulatory standpoint, gasses are considered processing aids and not food additives and as such, their use is not listed on the label ingredient statement (Cornforth and Hunt, 2008).

2.4 Goat, Goat Carcass, and Goat Meat Properties

2.4.1 Live Goat Carcass

The growth and development of goats is highly variable with genetic and environmental influences of breed, sex, nutrition, growth-promoting agents, and climate. Goat breeds vary in size ranging from small tropical breeds to large European breeds. The specialized meat-producing Boer goat is the largest, reaching up to 100 kg in body weight (Warmington and Kirton, 1990). The body compositions of goats change markedly during growth with muscle and fat increasing and bone decreasing with the progression of maturity (Warmington and Kirton, 1990).

Fat is the most variable tissue in the carcass and increases at a rate higher than the entire carcass, whereas muscle grows at a similar rate and bone at a lower rate (Sumarmor, Pratiwi and Murray, 2007). This causes lean:bone, tissue:bone, and fat:lean ratios to increase as chronological age and body weight increase (Aimerman, Domingo and Lanari, 2008). Differences in bone and soft tissue distribution in the carcass can affect carcass conformation, composition and the marketability of meat (Sumarmor, Pratiwi and Murray, 2007).

Some areas of the live carcass mature at different rates than others. When muscle groups situated in the hindquarters and those in distal limbs grow at a slower rate and decrease as a proportion of total muscle weight, this indicates that they are early maturing (Mahgoub, Kadim and Webb, 2012).

Sex and related sex hormones also play a major role in live goat development. Male goats often reach puberty at 4-8 months; female goats reach puberty at 7-10 months. Castration is widely practiced as a management practice to reduce the goat male odor, aggression, and alter the body composition (Sumarmor, Pratiwi and Murray, 2007).

Goats can be evaluated with live linear body measurements. These measurements are recognized as preferable objective measurements and have been used as a predictor of goat body composition. Age, breed, live weight and diet influence goat live body and carcass measurements (Kadim et al., 2006).

These measurements are of great value as goats are sold on a weight basis. Therefore, the economic value of goat carcass characteristics depends on its yield of meat as well as the cutting and processing quality of the meat. The linear measurements reflect the proportions of the body dimensions of the live animal to describe the changing body shape in order to predict both animal live weight and composition. These measurements can give a good indication of the final carcass composition (Mahgoub, Kadim and Webb, 2012).

2.4.2 Carcass Traits

Goat carcasses are thin and shallow and not as compact as in other meat-producing animals. However, goat carcasses become thicker and more compact as carcass weight increases (Kadim et al., 2006). The distribution of meat, bone and fat is extremely important in determining carcass quality, value and marketability.

Goats are leaner than sheep with more fat distributed in the body cavity and less subcutaneous fat (Mahgoub, Kadim and Webb, 2012). Goat carcasses are considerably leaner than other livestock carcasses, chiefly because the fat tends to be concentrated around the viscera and is separated as offal at slaughter (Owen et al., 1978). Goat carcasses usually have patch coverage of fat less than 2-3mm and consequently, they have a high lean content (Kadim and Mahgoub, 2012b). The greatest part of the body fat in goats is deposited in the abdomen at 40%, followed by subcutaneous fat at 30%, intermuscular fat at 23%, and mesenteric fat at 6%

(Wilson, 1960). This is due to internal fat such as omental and mesenteric fat developing faster in goats (Mahgoub, Kadim and Webb, 2012).

Bone proportions in the goat carcass range between 12% and 28% depending on the factors influencing it such as breed and sex. Carcass tissue distribution is influenced by stage of maturity, sex, breed, and nutrition (Mahgoub, Kadim and Webb, 2012).

Carcass weight is the best predictor of the meat content because of the lean nature of the carcass. (Kadim and Mahgoub, 2012b). While changes do occur with age, they are more of a function of changes in body weight, or more precisely, empty body weights. Smaller goats have a higher proportion of muscle, but a lower proportion of bone in the carcass than larger goats. Increased carcass weight results in increased fat percentage in both sexes (Mahgoub and Al-Busaidi, 2005).

Sex influences muscle distribution in goat carcasses, with males having a higher lean content in their carcasses, associated with more developed shoulder and neck, whereas female carcasses are leaner in the hind quarters. Intact males at 28 kg have been reported to have higher lean to fat to bone ratio (64:16:16) than females (62:21:13) (Mahgoub and Al-Busaidi, 2005), and castrated males have lower levels of carcass fat than females. Castrated male Boer goats have been found to have twice the amount of intermuscular and subcutaneous fat as intact male goats (Sumarmor, Pratiwi and Murray, 2007). Generally, female goats have higher fat content in their bodies than males and the portions of fat increase as body weight increases (Mahgoub and Lu, 1998; Mahgoub, Kadim and Webb, 2012). Castration in goats can have a significant effect on muscle distribution. Castrated carcasses had higher proportions of loin and hindquarters in the carcasses of crossbred Boer goats (Mahgoub, Kadim and Webb, 2012). Research found no significant differences in carcass dimensions between different sexes of mature goats except for

the eye muscle area, which was significantly greater in male than in female goats (Simela, Ndlovu and Sibanda, 1999). Carcass length, chest depth, thigh circumference and eye muscle area significantly increased with age of male goats, while fat depth over the eye muscle did not vary with age (Simela, Ndlovu and Sibanda, 1999).

Imported feral goat carcasses from Australia had superior conformation with the same amount of external fat, higher percentages of total primal cuts and lower percentages of total boneless meat as carcasses from goats raised on pasture (Nutti, Pinkerton and McMillin, 2003).

Low fat cover and low fat content cause a negative effect on the storage properties of goat carcasses with reports of 5.3% and 6.1% cold storage loss in male and female feral goats, respectively, which is higher than that of other species (Kirton, 1970). This is largely because of the lack of variation in subcutaneous and intermuscular fat in goat with age, due to the inherent low priority of fat deposition in the carcass (Simela, Ndlovu and Sibanda, 1999).

Most of this loss occurs during the chilling process. The chilling process removes heat from the carcass but also removes moisture, so the shrinkage from carcass chilling may be 3-5% of the initial hot carcass weight (McMillin, 2010).

Dressing percentage may also have a large degree of variation. It can be rather difficult to compare values of dressing percentages from different studies because different methods of slaughter are applied (e.g. kidney, kidney fat, head removal). Values vary between 44% and 55%. The dressing percentage is lower for male than female goats with this difference increasing with age (Mahgoub and Al-Busaidi, 2005). Removal of the head will result in 5-7% less dressing percentage (McMillin, 2010). Dressing percentage rises with increasing slaughter weight and length of feeding period. Dressing percentages of kid and yearling male and female

meat goats with different body conformations were relatively constant at 48-52% when the goats were withheld from feed overnight before harvest (McMillin et al., 1998).

Having an understanding of all of the factors attributed to goat carcass characteristics has allowed the ability to evaluate carcasses by assessing the conformation and distribution of muscle and fat in the carcass. Carcass quality characteristics can be evaluated by assessing the conformation of the carcass and the amount of distribution of muscle and fat in a carcass (Kadim and Mahgoub, 2012b).

2.4.3 Carcass Evaluation

Carcasses of meat animals are often evaluated to determine the relative ratios of lean, fat, and bone, and to provide an estimation of the palatability of the meat to be produced. Even though there are no official USDA grades for goat carcasses as for other major livestock species, it is useful to classify goat carcasses into groups for marketing and pricing (McMillin and Pinkerton, 2008). Selection classifications give an indication of the ratio of muscle to fat and bone and the relative amount of meat that may be obtained from the carcass:

- Selection 1 – Goat carcasses in selection 1 have a superior meat conformation and give the highest meat:bone ratio and lean meat yields. The carcass has thick leg muscling, bulging outside leg muscling, full muscling along the back and through the loin and rib, and thickness in the loin and leg junction and shoulder.
- Selection 2 – Goat carcasses in selection 2 have moderate muscling, with slightly thick and slightly bulging leg muscles, slightly full *Longissimus dorsi* muscling in the loins and ribs slightly thick shoulders, and lack of muscling in the loin and leg junction.

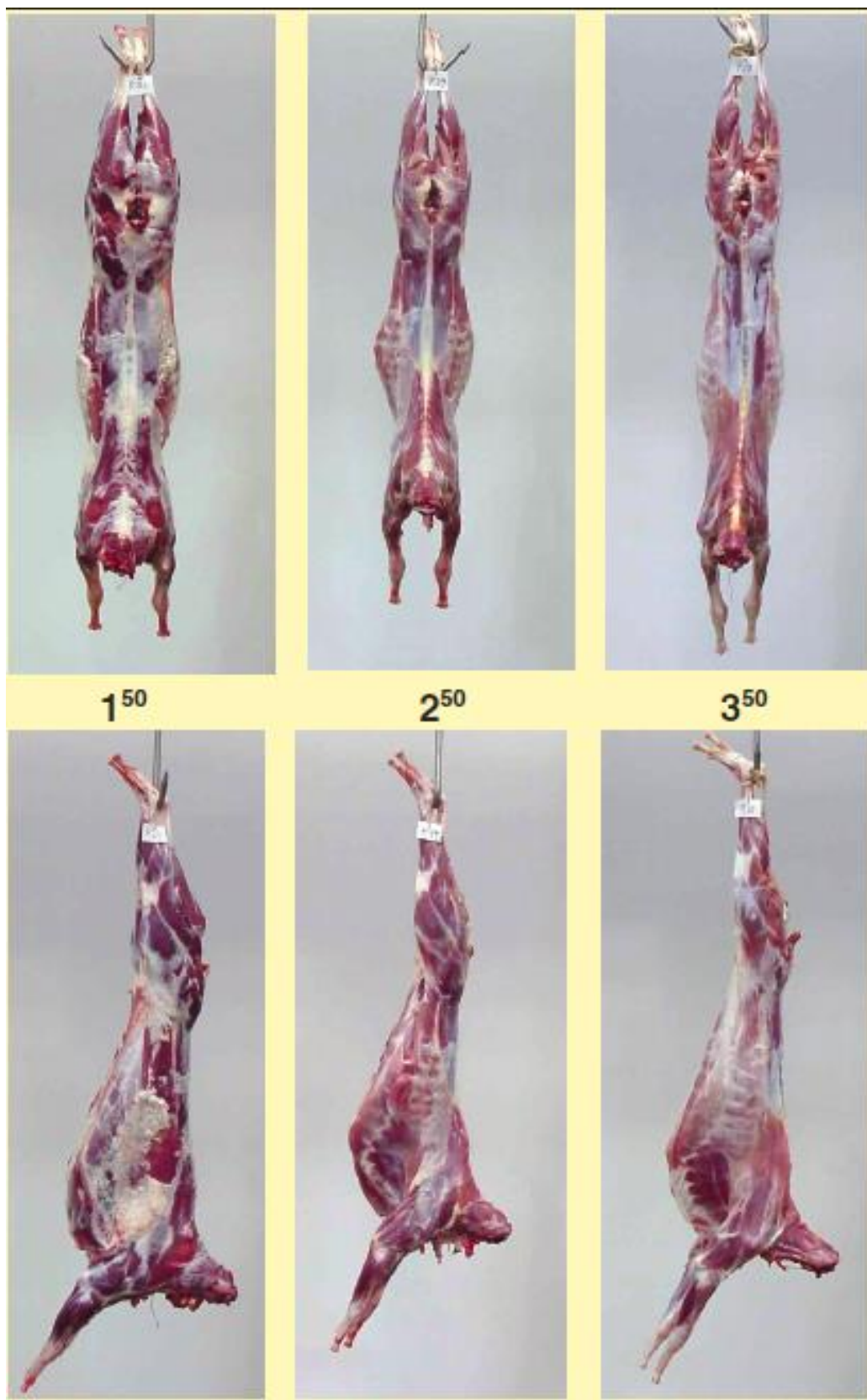


Figure 4. Goat carcass evaluation selection classifications.

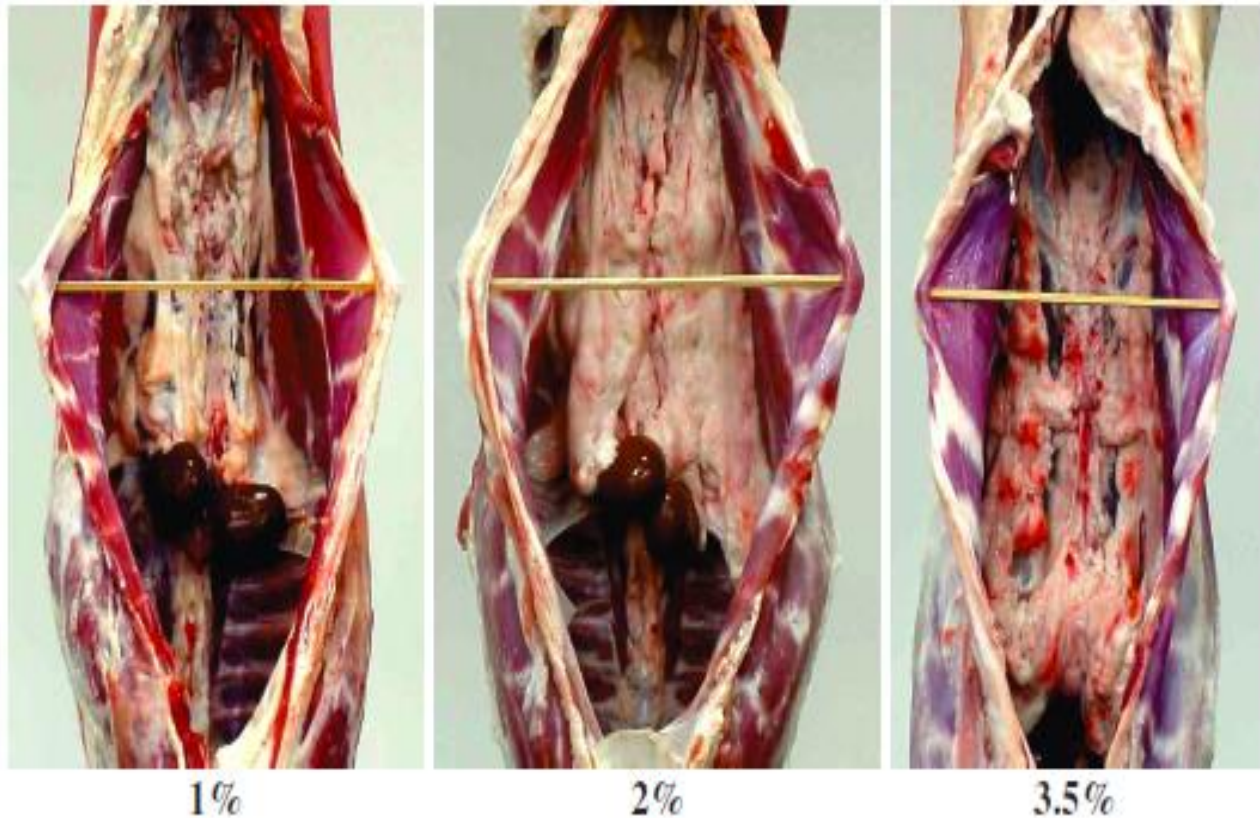


Figure 5. Kidney, pelvic, and heart fat scores.

- Selection 3 – Goat carcasses in selection 3 have deficient muscling and produce low yields of lean meat relative to the body size and weight. The carcasses are narrow and lack depth with moderate leg muscling, shallow rib and loin muscling, and slightly thin shoulder muscling. The deficient muscling may contribute a shrunken appearance of the carcass and a well-defined depression along the top of the back and at the junction of the loin and leg.

These selection classifications are used by the Institutional Meat Purchase Specifications for Fresh Goat (USDA, 2001) and are illustrated by Figure 4.

It should be noted that within each selection, a score of 1-99 may be assigned for added differentiation, making a carcass evaluation of 199 the highest possible evaluation score and an

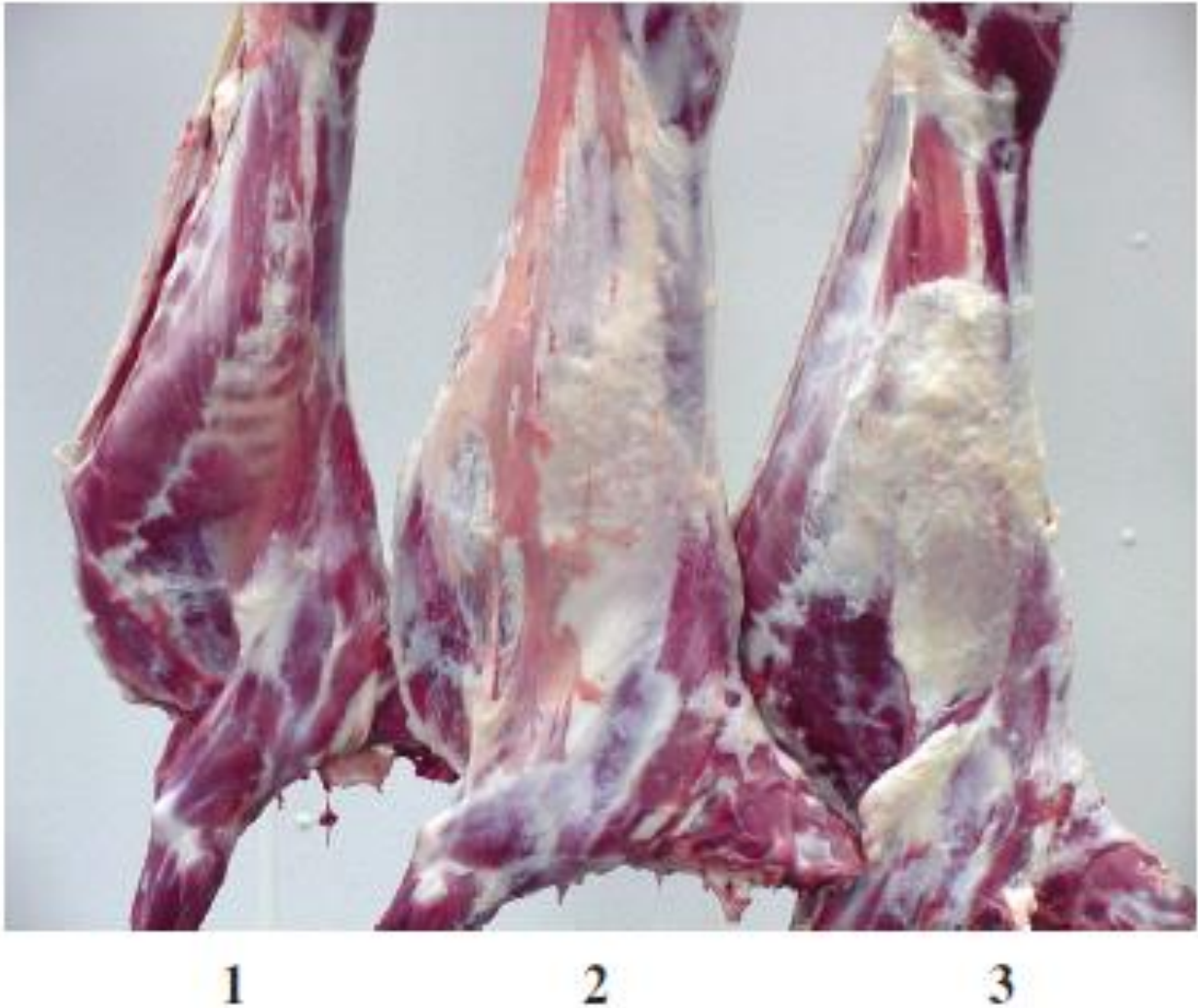


Figure 6. Goat subcutaneous fat cover scores.

evaluation of 301 the worst possible evaluation. These evaluations are used to gauge the degree of muscling in the goat carcass, as opposed to the cross-sectional area of the *Longissimus dorsi* due to it usually being insufficient in size to accurately measure (McMillin and Pinkerton, 2008).

Carcass yield of goat carcasses is highly related to the amount of kidney, pelvic, and heart (KPH) fat and subcutaneous fat because these are generally regarded as waste and not used for goat meat. KPH can be estimated by visual evaluation of the internal carcass fat as shown in Figure 5.

Goats do not generally deposit fat over the *Longissimus dorsi* as do lambs, cattle, and pigs. The low proportion of subcutaneous fat on goat carcasses makes subcutaneous fat thickness measurements a poor criterion for meat yield (Webb, Casey and Simela, 2005). Because of this low level of subcutaneous fat, fatness over the ribs and behind the shoulder is used as a relative indicator of waste fat that will be trimmed from the carcass, which will lower meat yield. A subjective estimation of the subcutaneous fat covering is made for goat carcasses rather than an objective linear measurement because the fat deposition pattern is not uniform over the body, making it difficult to accurately measure the thickness of the fat covering. The three degrees of fat cover scores are in Figure 6 (McMillin and Pinkerton, 2008).

2.4.4 Goat Meat Properties

Many factors affect the properties of postmortem goat meat. The tenderness and color properties of chevon have been found to be highly dependent on postmortem pH and temperature attained by the carcasses, with fast pH decline and slow chilling improving the tenderness and color (Simela, Ndlovu and Sibanda, 1999).

In goats, tenderness is highly influenced by crosslinking of collagen and muscle fibers, with collagen content higher, solubility lower, muscle fibrils thicker, and bundles larger than sheep, giving a coarse texture (Webb, Casey and Simela, 2005). These proportions of crosslinked collagen in muscle cause a decrease in collagen solubility upon cooking, which decreases tenderness (Warmington and Kirton, 1990). Tenderness in goat, as in other species, can be improved through aging as Warner-Bratzler shear values were found to be less with 6 days of aging than 1 day of aging of *Longissimus*, *Biceps femoris*, *Semimembranosus*, and *Semitendinosus* (Kannan et al., 2003). Aging for 3 days, however, was not shown to improve

tenderness, whereas aging for 14 days decreased shear force of *Gluteobiceps* muscles from 11 kg goat carcasses (King et al., 2004).

Factors such as age of a goat when harvested have also been found to decrease tenderness and juiciness (Warmington and Kirton, 1990). This is supported by research that found tenderness of muscles from yearling goats to be less than of kid goats (McMillin et al., 1998). The aforementioned conformation score of a goat carcass also appears to be correlated to tenderness, as the leg slices in meat from yearling goats and kid goats with low conformation were less tender than leg meat from kid goats having medium or high conformations (Phelps et al., 1999). As tenderness relates to sex of the animal, leg and back muscles from female goats had lower shear force and would be expected to be more tender than the same muscles from wethers and intact males (Johnson et al., 1995). Other factors of breed, muscle type and processing conditions can also influence shear force and tenderness (Webb, Casey and Simela, 2005; Kannan, Kouakou and Gelaye, 2001).

After tenderness, juiciness is widely considered the second most important quality of palatability (Aberle et al., 2012). Increased age of goat was also reported to increase drip loss, with the meat from older animals being judged to have lower initial and sustained juiciness than goat meat from younger animals (Schonfeldt et al., 1993). More water has been shown to be lost from goat meat cuts through longer storage periods (Morales-delaNuez et al., 2009; Morales-delaNuez et al., 2011).

There are multiple factors that can cause color to be less desirable in fresh goat meat. In two-hour transportation, stress pre slaughter did not alter water-holding capacity or shear force, but it decreased redness and chroma values in meat from young goats. Older goats were more resistant to transportation stress, however, and showed no effect on chroma values of loin cuts

(Kannan et al., 2003). Diet has been shown to be able to affect the lightness (L^*) of meat, however the redness was unaffected in those studies (Lee, Kouakou and Kannan, 2008).

2.4.5 Packaging and Storage Effects on Goat Meat

Color and other shelf-life characteristics decline with increased storage time. Shoulder cuts were the most red with the highest chroma and lowest hue. Surface discoloration of all packaged cuts occurred within 4 to 8 days, which is similar to the case-life of other species. Leg, shoulder/arm, and loin/rib cuts packaged in vacuum were slightly more tender than those in air-permeable film, with lower shear force in *Longissimus* than in *Semimembranosus* and in *Triceps brachii* (Kannan, Kouakou and Gelaye, 2001). Lean color score and overall appearance decreased as surface discoloration increased during 4-day storage of goat rib chops in retail overwrap packaging at 2°C, but there was no breed influence on these traits (Oman et al., 1999; Kannan, Kouakou and Gelaye, 2001).

Vacuum and MAP (30:30:40 mixture of $N_2:O_2:CO_2$) packaging of fresh goat meat increased L^* at 5 days of storage. After 5 days, L^* in vacuum began to decrease with MAP remaining constant (Morales-delaNuez et al., 2011). Another study found goat meat in MAP (10:70:20 mixture of $N_2:O_2:CO_2$) and vacuum packaging to be significantly lighter (higher L^*) on day 3, with meat in atmospheric air, MAP, and vacuum packaging being lighter than their initial values on day 5. MAP and vacuum packaging also resulted in lighter meat than atmospheric air on day 5 (Morales-delaNuez et al., 2009). Neither study found a packaging treatment effect on the a^* coordinate before 7 days, nor storage time effect on a^* with storage of 3 days. At 5 days, b^* coordinate was unchanged in vacuum packaging, however b^* was significantly higher in atmospheric air and both MAP gas concentrations (30:30:40 and 10:70:20 mixtures of $N_2:O_2:CO_2$) by day 3. MAP and vacuum treatments had a higher percent of drip loss

in the packages than did atmospheric air packaging at 3 days. WHC also increased with storage time across all packages, pointing to an inverse relationship, as meat lost more water during storage, decreasing the ability of meat to expel water on compression (Morales-delaNuez et al., 2009; Morales-delaNuez et al., 2011).

Longer shelf life of goat meat can be achieved with specific types of packaging. Vacuum packaging lengthened the shelf-life 28 days compared with aerobic packaging life of 3 days when comparing packs of minced goat meat (Babji, Murthy and Anjaneyulu, 2000). MAP also holds promise to greatly extend shelf life (McMillin, 2008).

CHAPTER 3: CARCASS EVALUATION AND CARCASS YIELD DIFFERENCES

3.1 Introduction

Carcasses of meat animals are often evaluated to determine the relative ratios of lean, fat, and bone, and to provide an estimation of the palatability of the meat to be produced (McMillin and Pinkerton, 2008). Carcass tissue distribution is influenced by multiple factors, such as stage of maturity, sex, breed, and nutrition (Mahgoub, Kadim and Webb, 2012).

It has been reported that imported feral goat carcasses from Australia had superior conformation with the same amount of external fat, higher percentages of total primal cuts, and lower percentages of total boneless meat as carcasses from goats raised on pasture (Nutti, Pinkerton and McMillin, 2003).

The present study was designed to evaluate carcass differences and carcass yield differences by comparing primal cut yields from representative frozen Australian goat carcasses and from representative United States kid goats after both fresh and frozen storage. Yields were compared both as a percentage of side and a percentage of carcass to take thaw loss of frozen sides into account.

With the previous research in mind, the hypotheses were that frozen United States goat meat carcasses would have higher percentages of primal cuts than frozen Australian goat carcasses and that United States goat carcasses would have higher conformation, fat and flank color scores when evaluated. Finally, a negative effect on overall yield and cut yield when comparing the frozen domestic goat meat with the fresh domestic goat meat was expected.

3.2 Materials and Methods

3.2.1 Animal Use

Institutional animal care and use committee approval was not obtained because all carcasses were obtained from approved state inspection abattoirs or from licensed meat brokers.

3.2.2 Apparatuses

Butcher Boy band saw (model SA20-F, Lasar Mfg. Company, Inc. Los Angeles, Ca)

3.2.3 Goat Side Samples

Two groups of 20 kid meat goats (n=40) were purchased from local domestic sources and two groups of 20 frozen Australian goat carcasses (n=40) were obtained from a commercial importer. All four groups would be reduced to a uniform number of carcasses (n=15 per group) after harvest and carcass evaluation.

Both groups of domestic kids were comprised of a variation of buckling and doelings, mainly of Boer and Spanish breed types. The first group was sourced from a local processor who obtained them from Texas sources. The second group produced by a Mississippi goat producer was purchased from a Mississippi processor. After being held off feed for one day with water always being accessible, goats were transported to the LSU abattoir for harvest. Goats were humanely slaughtered under Louisiana state meat inspection program supervision.

After overnight chilling at 4°C, for 24 hours, carcass conformation was evaluated independently by two trained meat scientists and estimates of the kidney, pelvic and heart fat (KPH), flank color and fat score were recorded. All measurements were taken using standard guidelines (McMillin and Pinkerton, 2008). After removing carcasses with spool joints, the most uniform carcasses (n = 30) were then selected based on the carcass evaluation. Spool joints are

an indication of older animals due to greater conversion of cartilage to bone within the joint (Aberle et al., 2012).

Fabrication began with the neck being removed from the carcasses using a Butcher Boy band saw. Carcasses were split along the vertebral column into left and right sides with the band saw. The neck and each side were weighed. The reason for removal of the neck prior to splitting was to achieve a more uniform division between sides, as the neck can be hard to control safely while attached to the carcass during sawing into sides. Left sides were then fabricated as fresh domestic sides. Right sides were wrapped in multiple layers of 0.6 mil polyvinyl chloride (PVC) barrier film before being frozen in a -33°C blast freezer and stored for 6 weeks until thawed. Thawing occurred with the carcass hung from hooks in an open air cooler at 4°C for 72 hours.

Every effort was made to replicate the freezing conditions of the frozen Australian carcass reported by the Australian processor. PVC was applied in the same manner as for the Australian carcasses, with the exception that the frozen domestic sides were frozen as only sides of a carcass which could have affected freezing rates. This confounding variable was outweighed by the need to compare fresh and frozen sides of the same carcasses.

The kidney, pelvic and heart fat (KPH) were removed from the fresh domestic sides and weighed. Then the sides were cut according to USDA Institutional Meat Purchase specifications Hotel style with an additional straight cut immediately anterior to the femur-pelvic joint (as shown in IMPS Food Service style) (USDA, 2001). The additional cut removed the sirloin portion from the leg for a later experiment. An example of this fabrication style can be observed in Figure 7.



Figure 7. USDA IMPS Hotel style with an additional straight cut immediately anterior to the femur-pelvic joint.

The weight of each cut (loin plus sirloin, rack, leg, hind shank, rib, shoulder, and fore shank) was obtained. The trotters along with miscellaneous bone fragments, connective tissue, and fat trimmed from the cuts were deemed as waste.

Two groups of 20 frozen Australian goat carcasses (n=40) were obtained from a commercial importer and transferred to a -33°C storage freezer upon receipt. After slaughter in the Brooklyn, Victoria, Australia plant, the carcasses were chilled for approximately 8 hours (4°C), wrapped in multiple layers of PVC with a netting over each carcass, then blast frozen for approximately 24 hours at -30°C before being loaded into shipping containers at -21°C. Transit time from Australia to the Philadelphia, Pennsylvania, U.S.A., port of entry was 4 weeks (Ovenden, 2013). Sides were then shipped in a cold storage transit truck to the LSU meat laboratory facility in Baton Rouge, LA. Sides arrived wrapped in multiple layers of PVC with each carcass inside of a protective netting. After arriving at the LSU meat laboratory, sides were kept in frozen storage at -33°C for an additional 2 weeks for a total of 6 weeks frozen storage.

Frozen imported carcasses and frozen domestic sides were hung and thawed in a storage cooler at 4°C for 3 days. After hanging from hooks, the PVC was removed from sides and carcasses exposing the surface of the carcass during the 3 day thawing process. After thawing, Australian carcasses were evaluated for the same criteria as the domestic carcasses (McMillin and Pinkerton, 2008). Following evaluation, Australian carcasses were weighed, the neck removed and weighed, and then carcasses were split along the vertebral column into right and left sides. Right sides were weighed and retained for the remainder of the experiment. After the three day thawing period, domestic sides were weighed and fabricated. Fabrication for both frozen domestic and frozen Australian occurred on the third day of thawing 6 weeks postmortem.

3.2.4 Statistical Analysis

Prior to data analysis, all weights were converted to percent of carcass and percent of side (thawed side for frozen carcasses) for comparative purposes. Data was compared as both a percentage of side weight and a percentage of carcass weight as the percentage of side weight accounted for any difference in weight due to thaw loss from the frozen sides.

All data was analyzed with SAS 9.4. Weight and evaluation scores were compared for domestic and imported carcasses using the Proc TTest function. Primal cut yield data was analyzed with Proc GLM for comparison of group means using the Tukey function. Paired T-tests were conducted for fresh domestic and frozen domestic sides from the same carcass. Paired data was analyzed using the Proc Paired TTest function. Significance for all statistical analyses was determined at $P < 0.05$.

3.3 Results and Discussion

Means and standard error of carcass traits for United States domestic and Australian Imported goat carcasses are in Table 1. Domestic carcasses had higher ($P < 0.05$) mean weights

than the imported Australian carcasses, with Australian carcasses having a lower ($P<0.05$) fat score, which indicated that the carcasses were leaner. Conformation score and flank color between the two groups were not different ($P>0.05$).

Table 1. Means and S.E.M. of carcass traits for United States domestic and Australian imported goat carcasses

Trait	U.S. domestic	Australian imported
Carcass weight, kg	15.49 ^a	13.76 ^b
S.E.M.¹	1.12	1.77
Conformation score²	236.67 ^a	243.67 ^a
S.E.M.¹	7.43	5.33
Flank color²	180.00 ^a	178.33 ^a
S.E.M.¹	6.25	6.36
Fat score²	1.79 ^a	1.69 ^b
S.E.M.¹	0.18	0.49

¹Standard error of mean

²Values are a subjective score

^{ab}Means in the same row lacking a common superscript letter differ ($P<0.05$)

Means and standard error of primal cuts as percentages of fresh domestic, frozen domestic and imported Australian thawed side weights without neck or kidney, pelvic, and heart fat are in Table 2. There were no differences ($P>0.05$) in percentages of loin, rack and leg between frozen domestic and frozen Australian goat carcasses. The percentages of rack and leg for frozen domestic and frozen Australian were different ($P<0.05$) than for the fresh domestic cuts, but there were no differences ($P>0.05$) in percentages of rib and fore shank among the three groups. Australian goat carcasses had higher ($P<0.05$) percentages of hind shank and shoulder than the domestic fresh and frozen carcasses. Waste was a higher ($P<0.05$) percentage of domestic fresh and frozen carcasses than the Australian frozen carcasses.

Means and standard errors of primal cuts as percentages of carcass weights without neck or kidney, pelvic, and heart fat are in Table 3. Primal cuts as a percentage of carcass weight were not different ($P>0.05$) for rib and hind shanks. Loins, hind shanks and shoulders were a higher ($P<0.05$) percentage of the thawed Australian side weights than the fresh or frozen domestic sides. Australian frozen and domestic frozen racks were a higher ($P<0.05$) percentage of carcass than fresh domestic sides. These percentages were similar to those reported previously for domestic and imported goat carcass cut yields (Nutti, Pinkerton and McMillin, 2003). Australian frozen and thawed sides also had less waste than domestic frozen and thawed or unfrozen goat carcass sides.

Table 2. Means and S.E.M. of primal cuts as percentages of thawed side weights without neck or kidney, pelvic, and heart fat

Primal cut	Fresh Domestic	Frozen Domestic	Frozen Australian	S.E.M.¹
Loin	13.67 ^a	13.75 ^{ab}	14.21 ^b	0.002
Rack	7.67 ^a	8.53 ^b	8.56 ^b	0.002
Leg	20.16 ^a	20.95 ^b	20.42 ^{ab}	0.003
Hind shank	3.50 ^a	3.42 ^a	3.98 ^b	0.001
Rib	13.66 ^a	13.05 ^a	12.41 ^a	0.003
Shoulder	26.77 ^a	26.4 ^a	29.38 ^b	0.003
Fore shank	4.67 ^a	4.53 ^a	4.29 ^a	0.001
Waste²	9.63 ^a	9.25 ^a	6.41 ^b	0.002

¹Standard error is reported as the average for the combined 3 treatments

²Waste is all separable bone, connective tissue, and fat. Does not contain KPH

^{ab}Means in the same row lacking a common superscript letter differ ($P<0.05$)

Paired comparisons indicated that fresh domestic right sides weighed more ($P<0.05$) than the fresh domestic left sides. The reason was likely not because there were true differences in side

weights, but because cutting goat carcasses into identical sides with a band saw is difficult. Left and right side symmetry was reported for beef carcasses (Butler, Garber and Smith, 1956). Weight of fresh domestic left sides did not differ ($P>0.05$) from frozen and thawed domestic right sides.

Table 3. Means and S.E.M. of primal cuts as percentages of carcass weights without kidney, pelvic and heart fat

Primal cut	Fresh Domestic	Frozen Domestic	Frozen Australian	S.E.M.¹
Loin	6.23 ^a	6.33 ^a	6.68 ^b	0.001
Rack	3.50 ^a	3.93 ^b	4.03 ^b	0.001
Leg	9.18 ^a	9.63 ^b	9.59 ^{ab}	0.001
Hind shank	1.59 ^a	1.56 ^a	1.87 ^b	<0.001
Rib	6.22 ^a	6.00 ^a	5.84 ^a	0.001
Shoulder	12.19 ^a	12.16 ^a	13.81 ^b	0.002
Fore shank	2.13 ^a	2.07 ^a	2.01 ^b	<0.001
Waste²	4.39 ^a	4.26 ^a	3.01 ^b	0.001

¹Standard error is reported as the average for the combined 3 treatments

²Waste is all separable bone, connective tissue, and fat. Does not contain KPH

^{ab}Means in the same row lacking a common superscript letter differ ($P<0.05$)

For a retail meat establishment a higher percentage of carcass cuts would obviously have its benefits. The benefits could be greatly outweighed, however, if it is necessary to buy frozen carcasses and incur the weight loss that is accompanied with the thawing process as carcasses and meat are almost always sold on a per weight basis.

3.4 Conclusion

Australian goat carcasses appeared to be leaner than that those of their market ready domestic counterparts, while their conformation scores and flank color did not differ. Furthermore, freezing carcass sides caused a significant decrease in carcass side weight after

thawing. It is also observed that freezing and thawing can cause different primal cuts to change as a percent ratio when compared to their side or to the cold carcass weight. These percentages were similar to those reported previously for domestic and imported goat carcass cut yields (Nutti, Pinkerton and McMillin, 2003).

CHAPTER 4: QUALITY DIFFERENCES AMONGST GROUPS OF GOAT LEGS

4.1 Introduction

It has long been accepted that freezing reduces the meat quality and that consumers prefer meat that has not been frozen (Lagerstedt et al., 2008). When meat is frozen, the cell membranes are damaged, which results in a lower water holding capacity and a higher cooking loss and consequently a risk of less juicy meat (Wheeler et al., 1990).

Freezing can also have an effect on the color properties of meat. Past research has shown that L^* was affected by the freezing and thawing process, pointing toward a darkening (lower L^*) of meat after the freezing and thawing process (Muela et al., 2010).

Though the later loin and rib tests in this study will examine many of these properties, previous research has shown cooking losses were highest in leg cuts, intermediate in shoulder/arm cuts, and lowest in loin/rib cuts (Kannan, Kouakou and Gelaye, 2001). This lower expected yield coupled with the desire to quantify the effects of freezing on another highly valuable cut from the goat carcasses (McMillin and Brock, 2005) is the principle reason for this experiment.

The objective of this research was to determine differences in color, water holding capacity (WHC) and yields of leg primal cuts from fresh domestic, frozen domestic and frozen imported goat leg groups. The hypothesis was that fresh legs would have lower losses and water holding capacity as a result of more free water, and more desirable overall color values than frozen legs.

4.2 Materials and Methods

4.2.1 Apparatuses

Minolta Reflectance Spectrophotometer (model CM 508d, Konica Minolta, USA); Koch smoke house (Market Master, Model 32-00-45); Carver laboratory press (Model C, Wabash, IN); Topcon digital planimeter (Model KP-82N, Japan)

4.2.2 Leg Samples

This experiment was only performed on the first group of domestic goat (n=15) and the first group of imported Australian carcasses (n=15). Legs (n=45) were removed for all groups (fresh domestic, frozen domestic, frozen imported) during the carcass cutting described in the previous chapter, yielding 15 legs from each group.

The leg sample was removed by a straight cut immediately anterior to the ball of the femur, separating the leg from the sirloin and separating the shank from the leg with a cut above the stifle joint (USDA, 2001). After cuts were made, legs were vacuum packaged in 5 mil vacuum pouches (30.48 cm x 35.56 cm, Koch # 120-425) to prevent excess moisture loss and held overnight in a 4°C cooler. The legs were removed from the package the next day.

Fresh legs were 2 days postmortem and frozen legs were 1 day removed from completion of a three day thawing process making them 6 ½ weeks postmortem. Upon removal from the package, a post pack weight was taken. Drip loss was then calculated as post package weight divided by prepackage weight and then subsequently was converted to a percentage.

A 10-20g sample was taken from the surface of the *Semimembranosus*, and fat and connective tissue were removed by a trained worker to make a retail style leg cut. The sample was then set aside for later water holding capacity testing. After the sample was removed, the legs were given 5 minutes to bloom, then color was taken from the sampled area.

A precooking weight was obtained. Then, legs were cooked in a smoke house to an internal temperature of 70°C. Upon removal from the smoke house, legs were chilled overnight in a 3°C cooler on open air racks. The following day, samples were blotted dry and cooked weight was obtained. Water holding capacity of each leg was measured on the sample taken from the *Semimembranosus* by the Carver press method.

4.2.3 Leg CIELAB Color Measurements

A reflectance spectrophotometer to measure CIELAB L* (lightness), a* (redness/greenness) and b* (yellowness/blueness) was placed on the surface of each leg where the sample had been removed. The instrument was calibrated against ceramic white and black standard plates prior to each measuring session. The spectrophotometer aperture opening was 10.31 mm, illumination type D65, with optical geometry of 45° and an observer angle of 2°. Three random readings at different locations per sample were taken along the surface of the raw meat with the colorimeter set to record the average of three measurements and give the average of each reading for accuracy. Prepackage and post package chroma $C = (a^*^2 + b^*^2)^{1/2}$ and hue angle $HA = (\arctan(a^*/b^*))$ were calculated later in SAS 9.4.

4.2.4 Leg Cooking

The legs were cooked in three batches, grouped into five legs per batch by the numerical order of their tag number. Cooking was done in a Koch smoke house at a temperature of 82°C with 50% humidity. Cooking was completed when legs reached an internal temperature of 70°C. After cooking, the samples were chilled on wire racks in a 4°C cooler for 24 hr. before post cooked weights were obtained. The cook loss and total loss were then calculated as cook loss = $(\text{cooked wt.}/\text{precook wt.}) \times 100$ and total loss = $(\text{cooked wt.}/\text{prepackage wt.}) \times 100$.

4.2.5 Water Holding Capacity of Leg Sample

Water holding capacity of the *Semimembranosus* was obtained using the Carver press method (Sebranek, 1978). Samples of approximately 3 g were placed onto #4 filter paper between Plexiglas plates on a Carver laboratory press and subjected to 3000 psi of pressure for 3 minutes. Tests were performed in triplicate.

The areas of moisture and the meat were traced on the filter paper and later measured with a Topcon digital planimeter to the closest one-hundredth square inch and converted to square cm. Water holding capacity was calculated as total area divided by meat area with lower ratios indicating greater water holding capacity (Sebranek, 1978).

4.2.6 Statistical Analysis

Data was analyzed with SAS 9.4 Proc GLM for comparison of batch and group means using the Tukey function. Paired T-tests were conducted for domestic fresh and frozen counter parts. Paired data was analyzed using the Proc Paired TTest function. Significance for all statistical analyses was determined at $P < 0.05$.

4.3 Results and Discussion

Means and standard errors on influence of storage treatment and cooking batch on loss, relative water holding capacity, CIELAB color values, and tenderness are in Table 4.

There was no influence of batch within group ($P > 0.05$) for any parameter. Comparing Tukey means indicated that frozen imported legs had higher ($P < 0.05$) drip loss and cook loss, but had lower ($P < 0.05$) color values for L^* , a^* , b^* , chroma, and hue angle than the frozen domestic legs or fresh domestic legs. Lower ($P < 0.05$) L^* signifies darker meat while a lower ($P < 0.05$) chroma signifies less saturation of color. The lower ($P < 0.05$) hue angle is normally a desirable trait as it points to greater redness. However, with lower ($P < 0.05$) a^* (redness) values than other

groups, frozen Australian legs only had a lower hue angle due to lack of color saturation in b* (yellowness). Frozen Australian legs also had a lower ($P<0.05$) WHC ratio than did legs in the domestic groups, which indicates a greater relative water holding capacity, likely due to loss of unbound water in the drip during the thawing process. This is supported by research that found WHC increased with increased moisture loss during storage (Morales-de la Nuez et al., 2009).

Table 4. Means and standard errors on influence of storage treatment and cooking batch on loss, relative water holding capacity, CIELAB color values², and tenderness.

		COOK LOSS	DRIP LOSS	TOTAL LOSS	WHC	L*	a*	b*	Chroma	Hue angle
Fresh	Batch 1	16.01% ^a	0.40% ^a	24.71% ^a	2.52 ^a	39.33 ^{ab}	20.29 ^a	12.73 ^a	23.97 ^a	36.10 ^a
Domestic	Batch 2	14.50% ^a	0.36% ^a	20.86% ^a	2.42 ^a	41.02 ^a	17.25 ^{ab}	11.16 ^a	20.56 ^{ab}	37.24 ^a
	Batch 3	15.54% ^a	0.36% ^a	20.71% ^a	2.37 ^a	37.36 ^{ab}	19.67 ^a	11.69 ^a	22.89 ^a	33.80 ^{ab}
	All	15.02% ^E	0.37% ^E	22.09% ^E	2.44 ^E	39.24 ^E	19.07 ^E	11.86 ^E	22.47 ^E	35.52 ^E
Frozen	Batch 4	15.01% ^a	0.94% ^{a b}	21.55% ^a	2.46 ^a	34.39 ^{bc}	16.67 ^{abc}	10.05 ^{ab}	19.48 ^{abc}	34.38 ^{ab}
Domestic	Batch 5	13.48% ^a	0.79% ^{ab}	20.18% ^a	2.42 ^a	35.69 ^b	16.33 ^{abc}	9.60 ^{abc}	18.96 ^{abcd}	33.23 ^{ab}
	Batch 6	13.56% ^a	0.99% ^{ab}	21.75% ^a	2.42 ^a	34.88 ^{bc}	18.36 ^a	10.76 ^a	21.63 ^a	35.52 ^a
	All	14.02% ^E	0.91% ^E	21.16% ^E	2.43 ^E	34.99 ^F	17.12 ^E	10.14 ^F	20.03 ^E	34.38 ^E
Frozen	Batch 7	17.43% ^a	1.14% ^{ab}	24.64% ^a	2.21 ^a	29.03 ^d	12.17 ^c	6.56 ^{bc}	13.84 ^{cd}	30.94 ^{ab}
Australian	Batch 8	14.13% ^a	1.57% ^b	21.29% ^a	2.11 ^a	30.41 ^{cd}	13.32 ^{bc}	6.55 ^{bc}	14.86 ^{bcd}	28.07 ^b
	Batch 9	14.56% ^a	1.23% ^{ab}	21.72% ^a	2.06 ^a	30.32 ^{cd}	11.91 ^c	5.93 ^c	13.31 ^d	28.65 ^b
	All	15.37% ^E	1.31% ^F	22.55% ^E	2.13 ^F	29.92 ^G	12.47 ^F	6.35 ^G	14.00 ^F	29.22 ^F
Standard Error¹		0.01	.001	0.01	0.05	0.68	0.54	0.44	0.68	0.57

¹Standard error is reported as the average for the combined 3 treatments

²L* = lightness; a* = redness; b=yellowness; hue angle = $\tan^{-1}(b^*/a^*)$, where lower values indicated more redness; chroma = saturation index = $(a^{*2}+b^{*2})^{1/2}$.

^{a-d}Means for batches in the same column lacking a common superscript letter differ ($P<0.05$)

^{EFG}Means group (ALL) in the same column lacking a common superscript letter differ ($P<0.05$)

There were no differences ($P>0.05$) in properties between the fresh and frozen domestic legs with the Tukey comparisons except for L* and b*. However, when comparing the fresh and frozen domestic legs using paired t-tests, the frozen domestic legs had higher ($P<0.05$) drip loss

and cook loss. Color values for L*, a*, b*, chroma and hue angle were lower ($P < 0.05$) than the fresh domestic legs. The paired data of frozen domestic means and fresh domestic means showed that the means of frozen Australian legs more closely resembled those of the frozen domestic means. This indicates that the differences seen in frozen Australian carcasses are likely due to the freezing and thawing process as they closely aligned with the frozen domestic sides.

The differences in loss and the differences in color between the frozen and fresh samples are closely aligned with previous research done by Wheeler et al. (1990) and Muela et al. (2010). Both of these differences point to the undesirable effects related to frozen goat meat.

4.4 Conclusion

It was concluded that freezing and thawing of goat legs will increase drip and cook losses and decrease color values, resulting in less desirable characteristics than fresh domestic goat meat. It was also observed that means of frozen Australian samples resemble the means of frozen domestic samples more closely than those of the fresh domestic samples, leading to the conclusion that the differences in characteristics between the fresh domestic samples and frozen domestic samples was likely due to freezing and thawing.

CHAPTER 5: LOIN AND RACK STUDY

5.1 Introduction

In a 2013 survey, of the people surveyed who had purchased goat meat in the last year, 85.8% purchased cuts, 5% purchased live goats, and 9.2% purchased both. Goat eating consumers prefer chops and cubs over whole and half carcasses (Harrison, 2013). With loin and rib cops being considered the most valuable cuts in the carcasses (McMillin and Brock, 2005) and more frozen imported goat meat being consumed in the United States than ever before (Pinkerton and McMillin, 2015), an in-depth look at the effects of freezing across multiple retail packaging types was warranted.

As previously discussed in the leg study, when meat is frozen, the cell membranes are damaged, which results in a lower water holding capacity and a higher cooking loss, and consequently a risk of less juicy meat (Wheeler et al., 1990). Freezing can also have an effect on the color properties of meat. Past research has shown that L^* was affected by the freezing and thawing process, pointing toward a darkening (lower L^*) of meat after the freezing and thawing process (Muela et al., 2010)

Other research in goat meat has found packaging type and display time to have significant effects on color values and drip loss (Morales-delaNuez et al., 2009; Morales-delaNuez et al., 2011; Kannan, Kouakou and Gelaye, 2001).

While previous research has compared the differences in PVC, VAC and MAP (with both 70% and 30% O_2) (Morales-delaNuez et al., 2009; Morales-delaNuez et al., 2011), no research was found that examined at the effects of MAP containing carbon monoxide (CO). With carbon monoxide becoming a more common processing aid since its legalization in 2004 (Cornforth and Hunt, 2008), and with the desirable carboxymyoglobin effects with previously frozen meat not

being available in the literature, the effects MAP (0.5:19.5:80 mixture of CO:CO₂:N₂) were examined.

The present study was designed to compare losses, color, and Warner-Bratzler shear force of rib and loin chops from representative fresh domestic, frozen domestic and frozen Australian goat carcasses across three different packaging treatments of modified atmospheric packaging (MAP), vacuum packaging (VAC), and overwrap polyvinylchloride film (PVC). The hypotheses were that chops from fresh domestic goat would have less loss, more desirable color, and lower Warner-Bratzler shear force values compared to chops from frozen carcasses, and that the frozen domestic carcasses would mimic the traits seen in the frozen Australian carcasses. It was also thought that fresh domestic chops would have more desirable traits in all packages. Carbon monoxide at 0.5% was used in MAP packaging to determine if the thawed chops could overcome the discoloration due to freezing by the binding of CO with myoglobin to give a bloomed color.

5.2 Materials and Methods

5.2.1 Apparatuses

Butcher Boy band saw (model SA20-F, Lasar Mfg. Company, Inc. Los Angeles, Ca); Extech light meter (Extech instruments, model L085074, Burlington, Vt.); Multivac tray sealer (model T200, Kansas City, MO); Mocon Pack Check (Model 333, Mocon Inc., Minneapolis, MN); Turbovac vacuum packaging machine (Howden Food Equipment B.V., The Netherlands); Win Holt overwrapping packager (Win Holt Equipment Group Dallas, TX); Hotpoint broiler oven (Hotpoint Co., div. of General Electric Company, Chicago, IL); Texture Technologies (TI-HDi Texture Analyzer. Scarsdale, New York); Minolta Reflectance Spectrophotometer (model CM 508d, Konica Minolta, USA)

5.2.2 Gases

The gas cylinders were obtained from Air Liquide Co. (Baton Rouge, LA) and certified to be within $\pm 0.5\%$ of the indicated mixture: Gas 1 – Aligal 12 80% Nitrogen, 20% CO₂; Gas 2 – Aligal mixture 80% CO₂, 20% CO.

5.2.3 Samples

The loin and rack were taken from each of the sides from each group (fresh domestic, frozen domestic, frozen Australian) after retail cuts were made in the carcass experiment. Fresh domestic loins and ribs were 24 h postmortem, while frozen loins and ribs were 6 weeks post mortem and thawed 3 days after frozen storage. Carcass identification was maintained throughout so that fresh and frozen domestic counterparts could be paired in later analyses. Chops (8-mm thick) were cut from both the loins (n=6) and ribs (n=6) using the band saw with cuts perpendicular to the vertebral column. One loin and one rib chop were randomly assigned to 3 treatments (MAP, PVC, VAC) with 1 replication of each. Each package contained one loin and one rib chop from a carcass side for a total of 6 packages corresponding to each side.

This gave chops (n=1080), half of which were obtained from the ribs (n=540), and loins (n=540) of the carcasses. An even number of chops were obtained from the three storage treatment groups of fresh domestic (n=360), frozen domestic (n=360), and frozen imported Australian (n=360) carcass sides. Chops were randomly assigned to the three packaging treatments of PVC (n=360), VAC (n=360), MAP (n=360). When comparing group and package interactions, there were a total of nine group x packaging treatments of chops (n=120).

5.2.4 CIELAB Color Measurements

Color and weight were taken on all chops before packaging. A Minolta Reflectance Spectrophotometer was placed on the surface of each chop to measure CIELAB L* (lightness),

a* (redness), and b* (yellowness). The instrument was calibrated against ceramic white and black standard plates prior to each measuring session. The spectrophotometer aperture opening was 10.31mm, illumination type D65, with optical geometry of 45° and an observer angle of 2°. Three random readings at different locations per sample were taken along the surface of the raw meat with the colorimeter set to take each reading in triplicate for accuracy. Prepackage and post package chroma $C = (a^*^2 + b^*^2)^{1/2}$ and hue angle $HA = (\arctan(a^*/b^*))$ were derived later in SAS 9.4.

5.2.5 Packaging

The study observed the effects of three different types of packaging subjected to the same storage conditions over the three different groups of carcass treatments for both loin and rib chops. One loin and one rib chop were placed together in each package.

5.2.5.1 Modified Atmosphere Packages

The chops were placed on 8.47 cm x 15.24 porous soaker pads (Koch item # 1800 0124). MAP packages were #3 APT CR Fresh Lock meat trays (crystallized polyethylene terephthalate trays with a moisture vapor permeability of 31cc/m²/24hr and oxygen permeability of 75 cc/m²/24hr) and lidding film (Curlam, Curwood, New London, WI with a moisture permeability of 1.5/m²/24hr at 23°C and oxygen permeability of 0.1 cc/m²/24hr at 23°C) sealed on a Multivac tray sealer. Package head space volume was ≈1330cm³. Packages were filled with Aligal 12 (80% N₂, 20% CO₂) and then the Aligal mixture of 80% CO₂, 20% CO was injected through a septum using a 5 cc syringe until 0.5 % CO was achieved in the package. All packages were then checked for accuracy using a Mocon Pack Check. A piece of black electrical tape was placed over the septum to ensure there was no gas exchange from the packages during storage.

5.2.5.2 Polyvinyl Chloride Film Overwrapping

The chops were placed on 8.47 cm x 15.24 cm porous soaker pads (Koch item # 1800 0124) onto white 10.16 cm x 15.24 cm expanded polystyrene trays (Koch item # 1620 0548), and overwrapped with 0.6-mil PVC oxygen permeable film (Koch item # 7500 3815) with a Win Holt overwrapping packager.

5.2.5.3 Vacuum Packaging

The chops were vacuum packaged using a Turbovac vacuum packaging machine at 20mm vacuum in clear 20.31 cm x 30.38 cm 5mil standard barrier nylon-polyethylene pouches (Koch item #7600 0029) with 8.47 cm x 15.24 cm porous soaker pads (Koch item # 1800 0124) on one side.

5.2.5.4 Simulated Retail Display

Packages of chops were randomly placed on open air shelving for three days in a 3°C cooler under ≈ 170 lumens of florescent light. Light intensities for all package placements were measured using an Extech light meter. Packages were rearranged every day to minimize differences due to location. No outside light was allowed during storage. Storage time was set at 3 day as previous research indicated that 3 days was the maximum display shelf life for overwrap packaging before degradation of quality of the product. It was desired to have all packages compared under acceptable uniform conditions and so the 3 day display time was selected as representative of retail display conditions.

After removal from packages, chops were allowed 5 minutes to “re-bloom”. Color and weight were obtained for post display package values.

5.2.6 Cooking

The identification of chops was maintained throughout the study with a template containing the unique code for each individual chop. Chops were placed on an uncovered metal baking pan (43.18 cm x 63.5 cm x 2.54 cm) and cooked in a Hotpoint broiler oven at a surface temperature of 116°C to an internal temperature of 70°C. The broiler oven had an opening of 68.58 cm x 41.91 cm and was 59 cm deep. Samples were cooked at a distance of 17.78 cm from the radiant heat source. There were 64 chops cooked on each tray at each time determined by number and treatment. Five batches were cooked for each group (n=3) and replication (n=2). Trays were rotated at half of the cooking time to account for any oven hot spots. The cooking time and temperature were determined in preliminary tests with chops of the same dimensions as those in the present study.

5.2.7 Tenderness

Cooked chops were chilled for 2 hours to below 10°C to obtain a more uniform core sample on the chilled samples. One 12.7-mm diameter core was taken from the center of each chop parallel to the longitudinal orientation of the muscle fibers (Schonfeldt et al., 1993). Each core was sheared once with a Warner-Bratzler shear force attachment perpendicular to the longitudinal orientation of the muscle fibers of each core. The force to shear each core was measured using a Texture Technologies texture analyzer. The load cell was 25 kg, the crosshead speed was 100-mm per minute, and the peak force was measured in grams.

5.2.8 Statistical Analysis

Prior to data analysis, all weights for losses were converted to percent for comparative purposes. Loss, color and tenderness were analyzed with SAS (Version 9.4, SAS Inst. Inc., Cary,

NC) PROC GLM for comparison of group, pack, chop and combined group pack means using the Tukey function. Significance for all statistical analyses was determined at $P < 0.05$.

5.3 Results and Discussion

5.3.1 Group Comparison

Means and standard errors for the main effect of group (fresh domestic, frozen domestic and frozen Australian) without accounting for packaging treatments and chop type on loss, color and tenderness are in Table 5.

When comparing losses, fresh domestic chops had less ($P < 0.05$) drip loss, cook loss and total loss than frozen Australian and frozen domestic groups. Frozen Australian chops had less ($P < 0.05$) drip loss, cook loss and total loss than the frozen domestic group. Frozen domestic chops had greater loss when compared to frozen Australian chops, which could be due to larger thaw loss in Australian carcasses. These increased losses are likely because the cell membranes are damaged when meat is frozen, which results in a lower water holding capacity and a higher cooking loss, and consequently a risk of less juicy meat (Wheeler et al., 1990).

Pre-packaged fresh domestic chops had a higher ($P < 0.05$) L^* , b^* , and hue angle with lower ($P < 0.05$) a^* than frozen domestic and frozen Australian groups with a chroma that was lower ($P < 0.05$) than frozen domestic chops, but did not significantly differ from frozen Australian chops. Frozen domestic chops had higher ($P < 0.05$) L^* , b^* , and hue angle than frozen Australian chops, but a^* was not significantly different. Frozen domestic chops had a higher ($P < 0.05$) hue angle than both fresh domestic and frozen Australian chops. This would indicate that the fresh goat chops showed less redness, as represented by the low a^* , in addition to higher hue angle, and were lighter in color, as represented by the L^* , than frozen group chops. There was less saturation of color when compared to the frozen domestic counterparts. These

prepackaged values are especially useful in documenting differences in groups based on storage treatment, as packaging would not yet have an influence. Similar results on color of frozen and fresh meat have been reported on lamb; however, that freezing treatment was done during storage after the cut was made and not on the carcass (Brad Kim, Matilde and Rosenvold, 2011).

Post packaging measurements are averages of the three packaging treatments. Overall, the results were similar to the prepackaging results with only a^* and chroma being higher in the fresh domestic chops, but no other color changes among the groups. Fresh domestic chops had higher L^* , a^* , b^* , chroma and hue angle than chops from frozen groups. Frozen domestic chops had higher L^* , b^* , chroma and hue angle than frozen Australian chops, while the a^* did not significantly differ. This is the same relationship as for frozen Australian and frozen domestic chops in the prepackaged group. The higher chroma of fresh domestic chops was directly caused by the higher a^* value, which indicated a more saturated redness for that group. Frozen storage was previously shown to increase colorimetric parameters on L^* , a^* , b^* , and chroma while increasing hue angle (Vieira et al., 2009). It is important to note that this comparison of groups did not account for packaging treatment. The fresh MAP a^* treatment is largely responsible for the higher fresh domestic group a^* , as will be shown in the latter group package section.

Fresh domestic chops had the highest ($P<0.05$) Warner-Bratzler shear force values of all groups, with frozen domestic chops having higher ($P<0.05$) shear force values than frozen Australian chops. These findings agreed with those of Leygonie et al. (2012) that tenderness of meat as peak force is generally thought to decrease with freezing and thawing. The more desirable tenderness values for frozen Australian chops could be due to unstable temperature fluctuations in the shipping process which could have led to formation of larger ice crystals within the meat (Ranken, 2000). It should be noted that this study only measured mechanical

Table 5. Means and standard errors on influence of fresh domestic, frozen domestic, and frozen Australian chops on loss, color, and tenderness.

	Fresh Domestic	Frozen Domestic	Frozen Australian	S.E.M.¹
<i>Loss</i>				
Drip Loss	3.05 ^a	4.20 ^c	4.10 ^b	0.0009
Cook Loss	13.53 ^a	15.92 ^c	15.09 ^b	0.0013
Total Loss	16.18 ^a	19.44 ^c	18.57 ^b	0.0015
<i>Pre Pack²</i>				
L*	38.85 ^a	35.76 ^b	33.04 ^c	0.1218
a*	13.76 ^a	14.63 ^b	14.48 ^b	0.0684
b*	9.74 ^a	9.22 ^b	8.16 ^c	0.0571
Chroma	16.89 ^a	17.34 ^b	16.64 ^a	0.0806
Hue angle	35.52 ^a	32.09 ^b	29.22 ^c	0.1318
<i>Post Pack²</i>				
L*	39.74 ^a	35.83 ^b	33.17 ^c	0.1259
a*	15.18 ^a	14.70 ^b	14.61 ^b	0.0933
b*	10.56 ^a	9.53 ^b	8.38 ^c	0.0615
Chroma	18.56 ^a	17.64 ^b	16.88 ^c	0.0996
Hue angle	34.95 ^a	33.23 ^b	28.65 ^c	0.1662
<i>Tenderness</i>				
WB	4628 ^a	3936 ^b	2938 ^c	52.2069

¹Standard error is reported as the average for the combined 3 treatments

²L* = Lightness; a* = redness; b=yellowness; Hue angle = $\tan^{-1}(b^*/a^*)$, where lower values indicated more redness; Chroma = Saturation Index = $(a^{*2}+b^{*2})^{1/2}$.

^{abc}Means within the same row lacking a common superscript letter differ (P<0.05)

tenderness. Other research has shown that sensory panels found frozen meat tougher than unfrozen, while the mechanical shear forces indicated the opposite effect of freezing and thawing (Vieira et al., 2009), probably due to loss of moisture that may influence perceived tenderness.

In research conducted with beef steaks, samples from frozen cuts were found to be more tender by mechanical testing and less tender and less juicy by a sensory panel than that of the fresh cuts (Lagerstedt et al., 2008; Shanks, Wulf and Maddock, 2002). This is likely due to lower expressible moisture to aid in the process of mastication, which can give the sensation of toughness to the eater (Aberle et al., 2012).

5.3.2 Packaging Comparison

A comparison of the main effects of packaging (MAP, overwrap PVC, and vacuum) without considering the effects of storage group and chop on loss, color, and tenderness are in Table 6.

Vacuum packaging samples had significantly more drip loss in packages than did chops in MAP and overwrapping, which did not differ significantly ($P < 0.05$) from one another. This is likely due to the vacuum packaging opening up the pores of the meat and allowing unbound water to escape. These findings are in line with other studies comparing the effects of VAC and MAP in beef steaks (Huang, Chung and McMillin, 2005; McMillin et al., 1994) and in lamb (Muela et al., 2010). Cook loss was not significantly different with packaging. Total loss was greater ($P < 0.05$) for chops in vacuum packaging than overwrapping, but did not differ ($P < 0.05$) from chops in MAP, which did not differ ($P < 0.05$) from those in overwrap packaging.

L^* and b^* of chops did not differ ($P < 0.05$) with packaging treatment for any pre packed groups. Overwrapped chops did have lower ($P < 0.05$) a^* than vacuum, which caused lower ($P < 0.05$) chroma and hue angle than vacuum packaging. MAP did not differ ($P < 0.05$) from

either VAC or PVC for a^* , chroma or hue angle of chops. The lower a^* for the overwrapping group is currently unexplained and may be a Type I error due to randomization of chops among packaging treatments, but the numerical differences in a^* values were small.

Post package, there were no ($P < 0.05$) differences in L^* of chops with packaging treatment. Chops in MAP had a higher ($P < 0.05$) a^* than VAC and PVC with chops in VAC having a higher ($P < 0.05$) value than PVC. The higher a^* with MAP caused chops in MAP to have a higher ($P < 0.05$) chroma and lower ($P < 0.05$) hue angle than with VAC and PVC. PVC chops had a higher hue angle than with VAC, while the chroma did not differ ($P < 0.05$). Chops in MAP and PVC had higher ($P < 0.05$) b^* than VAC but did not differ ($P > 0.05$) from one another. The higher ($P < 0.05$) a^* with MAP is a result of the carboxymyoglobin red pigment in the MAP packaging. These results of MAP with CO are supported by fresh beef research that showed similar color value differences of meat in CO-MAP compared with overwrapping and vacuum packaging (Jayasingh et al., 2001). The lack of changes in L^* is also in line with research which found a minimum of 5 days to see packaging display effects on L^* (Morales-de la Nuez et al., 2009; Morales-de la Nuez et al., 2011).

Packaging type had no significant ($P > 0.05$) effect on Warner-Bratzler tenderness. This was possibly due to the short packaging duration of 3 days, as previous goat research has shown that 3 days of aging in goat cuts is insufficient to decrease shear force values whereas shear force may be decreased during 6 to 14 days of aging (King et al., 2004; Kannan, Kouakou and Terrill et al., 2003). Further research giving cuts additional aging time to decrease tenderness values would be needed to properly evaluate packaging effects on tenderness values.

Table 6. Means and standard errors on influence of packaging on loss, color, and tenderness.

	MAP	PVC	VAC	S.E.M. ¹
<i>Loss</i>				
Drip Loss	3.51 ^b	3.16 ^b	4.68 ^a	0.0009
Cook Loss	14.92 ^a	14.98 ^a	14.66 ^a	0.0013
Total Loss	17.90 ^{ab}	17.66 ^b	18.63 ^a	0.0015
<i>Pre Pack²</i>				
L*	35.94 ^a	35.78 ^a	35.93 ^a	0.1218
a*	14.47 ^a	14.07 ^b	14.34 ^{ab}	0.0684
b*	9.15 ^a	8.86 ^a	9.12 ^a	0.057
Chroma	17.16 ^a	16.67 ^b	17.04 ^{ab}	0.0806
Hue angle	32.09 ^a	32.09 ^b	32.09 ^{ab}	0.1318
<i>Post Pack²</i>				
L*	36.27 ^a	36.25 ^a	36.22 ^a	0.1259
a*	17.51 ^a	13.25 ^c	13.75 ^b	0.0922
b*	9.59 ^a	9.83 ^a	9.06 ^b	0.0615
Chroma	20.00 ^a	16.55 ^b	16.53 ^b	0.0996
Hue angle	28.65 ^c	36.67 ^a	33.23 ^b	0.1662
<i>Tenderness</i>				
WB	3855 ^a	3845 ^a	3803 ^a	52.2069

¹Standard error is reported as the average for the combined 3 treatments

²L* = Lightness; a* = redness; b=yellowness; Hue angle = $\tan^{-1}(b^*/a^*)$, where lower values indicated more redness; Chroma = Saturation Index = $(a^{*2}+b^{*2})^{1/2}$.

^{abc}Means within the same row lacking a common superscript letter differ (P<0.05)

5.3.3 Packaging Pre and Post Comparison

A comparison of pre and post packaging color values on chops across three different packaging (MAP, PVC, VAC) treatments, without accounting for chop type or storage group is in Table 7.

Table 7. Means and standard errors on influence of packaging on CIELAB color value² changes from pre to post package.

	Pre Package				Post Package			
	MAP	PVC	VAC	S.E.M. ¹	MAP	PVC	VAC	S.E.M. ¹
L*	35.94 ^a	35.78 ^a	35.93 ^a	0.1218	36.27 ^a	36.25 ^a	36.22 ^a	0.1259
a*	14.47 ^b	14.07 ^{b^c}	14.34 ^b	0.0684	17.51 ^a	13.25 ^c	13.75 ^d	0.0922
b*	9.15 ^b	8.86 ^b	9.12 ^b	0.057	9.59 ^a	9.83 ^a	9.06 ^b	0.0615
Chroma	17.16 ^b	16.67 ^{b^c}	17.04 ^{b^c}	0.0806	20.00 ^a	16.55 ^c	16.53 ^c	0.0996
Hue angle	32.09 ^c	32.09 ^c	32.09 ^c	0.1318	28.65 ^d	36.67 ^a	33.23 ^b	0.1662

¹Standard error is reported as the average for the combined 3 per pack treatments and the average for the combined 3 post package treatments

²L* = Lightness; a* = redness; b= yellowness; Hue angle = $\tan^{-1}(b^*/a^*)$, where lower values indicated more redness; Chroma = Saturation Index = $(a^{*2}+b^{*2})^{1/2}$.

^{abc}Means within the same row lacking a common superscript letter differ (P<0.05)

Prepackage L* values of chops did not significantly differ from prepackage L* values for any treatment. Post MAP packaging chops had higher (P<0.05) a* values than prepack a* values while post pack a* for chops in PVC and VAC were lower (P<0.05) than prepack values. Post package b* was higher (P<0.05) for chops in MAP and PVC, while chops in VAC did not differ (P>0.05) in b* from prepackage values. The higher post package a* values of chops in MAP caused a higher (P<0.05) chroma and a lower hue angle when compared to prepackaged values. Chroma of chops in PVC and VAC did not differ (P>0.05) from prepackage chroma values. PVC

and VAC chops post package did have higher ($P<0.05$) hue angles than chops prepackage, which signifies less desirable color (Hunt and King 2012).

5.3.4 Group Packaging Comparison

A comparison of storage group (fresh domestic, frozen domestic, and frozen Australian) carcasses combined with packaging (MAP, PVC, VAC) without accounting for the main effect of chop type for loss, color, and tenderness is in Table 8.

Frozen domestic chops had higher drip loss than frozen Australian chops, and frozen Australian chops had higher ($P<0.05$) drip loss than fresh domestic chops. On further analysis, the cause may be due to frozen domestic VAC and frozen Australian VAC chops having higher ($P<0.05$) drip loss than other storage and packaging combinations. There was no difference ($P>0.05$) in drip loss between frozen domestic VAC and frozen Australian VAC chops. Fresh domestic PVC chops had less ($P<0.05$) drip loss than frozen domestic chops in PVC.

Packaging had little effect on cooking loss or total loss, as all combinations closely followed the group values for storage treatment. All prepackaging color values closely followed the trends of the storage group as packaging treatments had not yet been implemented.

There were no differences ($P>0.05$) for L^* of chops post packaging within any storage group, as all fresh domestic packaging treatments had higher ($P<0.05$) L^* values than all frozen domestic packaging treatments, which had higher ($P<0.05$) values than all frozen Australian.

The post package value for a^* was higher for chops in MAP packaging within each storage group than those in PVC and VAC. Fresh domestic MAP chops had a higher ($P<0.05$) a^* values than frozen Australian MAP chops. The frozen domestic MAP treatment combination did not have different ($P>0.05$) a^* values in chops than chops in either fresh domestic MAP or

Table 8. Means and standard errors on differences between storage group and package combination on loss, color, and tenderness.

	Fresh Domestic			Frozen Domestic			Frozen Australian			
	MAP	PVC	VAC	MAP	PVC	VAC	MAP	PVC	VAC	S.E.M. ¹
<i>Loss</i>										
Drip Loss	3.16 ^{bc}	2.57 ^c	3.44 ^{bc}	3.70 ^{bc}	3.77 ^b	5.12 ^a	3.67 ^{bc}	3.14 ^{bc}	5.50 ^a	0.0009
Cook Loss	13.22 ^a	13.82 ^{ab}	13.59 ^{ab}	16.30 ^c	15.97 ^c	15.48 ^c	15.23 ^{bc}	15.16 ^{bc}	14.89 ^{bc}	0.0013
Total Loss	15.96 ^d	16.02 ^{dc}	16.54 ^{dc}	19.38 ^{ab}	19.14 ^{ab}	19.79 ^a	18.35 ^{abc}	17.82 ^{bcd}	19.54 ^{ab}	0.0015
<i>Pre Pack²</i>										
L*	38.78 ^a	38.73 ^a	39.03 ^a	35.79 ^b	35.65 ^b	35.84 ^b	33.26 ^c	32.95 ^c	32.92 ^c	0.1218
a*	13.79 ^{ab}	13.67 ^a	13.83 ^{ab}	14.85 ^c	14.43 ^{abc}	14.6 ^{bc}	14.76 ^c	14.12 ^{abc}	14.57 ^{bc}	0.0684
b*	9.71 ^a	9.68 ^a	9.82 ^a	9.39 ^{ab}	8.96 ^{cb}	9.33 ^{ab}	8.35 ^{cd}	7.93 ^d	8.2 ^d	0.057
Chroma	16.89 ^{ab}	16.79 ^{ab}	16.99 ^{ab}	17.61 ^a	17.02 ^{ab}	17.38 ^a	16.98 ^{ab}	16.21 ^b	16.73 ^{ab}	0.0806
Hue angle	34.95 ^a	35.52 ^a	35.52 ^a	32.09 ^b	32.09 ^b	32.66 ^b	29.22 ^c	29.22 ^c	29.22 ^c	0.1318
<i>Post Pack²</i>										
L*	39.53 ^a	40.05 ^a	39.65 ^a	35.82 ^b	35.63 ^b	36.03 ^b	33.45 ^c	33.07 ^c	32.98 ^c	0.1259
a*	18.16 ^a	13.57 ^c	13.81 ^c	17.36 ^{ab}	13.04 ^c	13.78 ^c	17.03 ^b	13.13 ^c	13.66 ^c	0.0933
b*	10.73 ^a	11.4 ^a	9.56 ^b	9.36 ^{bc}	9.68 ^b	9.57 ^b	8.68 ^{cd}	8.42 ^d	8.05 ^d	0.0615
Chroma	21.12 ^a	17.76 ^c	16.82 ^{cd}	19.76 ^b	16.28 ^{de}	16.87 ^{cd}	19.13 ^b	15.62 ^e	15.88 ^{de}	0.0996
Hue angle	30.37 ^e	40.11 ^a	34.95 ^c	28.07 ^f	36.67 ^b	34.95 ^{bc}	26.93 ^f	32.66 ^d	30.37 ^e	0.1662
<i>Tenderness</i>										
WB	4604 ^a	4666 ^a	4615 ^a	3941 ^b	3900 ^b	3967 ^b	3020 ^c	2968 ^c	2825 ^c	52.206

¹Standard error is reported as the average for the combined 9 group/package treatments

²L* = Lightness; a* = redness; b= yellowness; Hue angle = $\tan^{-1}(b^*/a^*)$, where lower values indicated more redness; Chroma = Saturation Index = $(a^{*2}+b^{*2})^{1/2}$.

^{a-f}Means within the same row lacking a common superscript letter differ (P<0.05).

frozen Australian MAP. The a^* values of chops in PVC and VAC did not differ ($P>0.05$) within or between any group.

The post package b^* values of chops closely followed those of the storage group with the only significant difference with group being the fresh domestic group chops. For fresh domestic chops, VAC resulted in lower ($P<0.05$) values than MAP and PVC.

The distributions for chroma and hue angle resembled those of a^* with chops in MAP having higher chroma and lower hue angle than in VAC and PVC within each group. Fresh domestic MAP chops had the highest ($P<0.05$) chroma and lowest ($P<0.05$) hue angle, with frozen domestic and frozen Australian chops not different ($P>0.05$) from one another.

Packaging had no significant effect on Warner-Bratzler shear force values within storage group, with all fresh domestic packaging treatments having higher ($P<0.05$) values for chops than all frozen domestic packaging treatments, which were higher ($P<0.05$) than all frozen Australian packaging treatments.

5.3.5 Group Packaging Pre and Post Comparison

A comparison of pre and post packaging color values on chops across three different packaging (MAP, PVC, VAC) treatments combined with storage group (fresh domestic, frozen domestic, and frozen Australian) carcasses without accounting for the main effect of chop type is in Table 9.

L^* values did not differ among chops in any storage group treatment pre or post package, however all pre and post package fresh domestic had higher ($P<0.05$) L^* values than all pre and post package frozen domestic chops, which had higher L^* values than all pre and post package frozen Australian chops. This further supports that L^* is affected by storage treatment only, with no effect from packaging treatment. This corresponded with previous research with other species

that found freezing method and storage time had no effect on L^* , but found L^* to be significantly lower in frozen treatments than fresh samples (Muela et al., 2010; Moore and Young, 1991). The effects of treatments on L^* of chops are further illustrated by Figure 8.

The fresh domestic post package MAP treatment had the highest ($P<0.05$) observed value for a^* and chroma in chops among all pre and post combinations. Frozen domestic and frozen Australian post package MAP treatment a^* and chroma values of chops did not ($P>0.05$) differ from one another, but were higher than all other observed pre and post a^* and chroma values except for those in fresh domestic post package MAP chops. These treatment combinations were the only a^* and chroma values to differ ($P<0.05$) from pre to post package. This is especially noteworthy, as frozen post package MAP treated with 0.5% CO gave a^* and chroma (color saturation) values higher than those of prepackaged fresh meat. The effects of treatments on a^* are further illustrated by Figure 9.

The only pre to post package increase ($P<0.05$) in b^* values of chops occurred in fresh domestic MAP and PVC. These values were higher ($P<0.05$) than all other treatment combination for b^* , but did not differ ($P<0.05$) from one another. The effects of treatments on b^* are further illustrated by Figure 10.

The post package MAP hue angle values of chops for all storage treatments were lower ($P<0.05$) than their respective prepackaged values, indicating a shift towards a more desirable red color. The post package PVC hue angle values for chops in all storage treatments and the post package frozen domestic VAC treatment were higher ($P<0.05$) than their respective prepackaged values, indicating a shift towards a less desirable red color. The effects of treatments on hue angle are further illustrated by Figure 11.

Table 9. Means and standard errors on differences between storage group and package combination on prepackage and post package CIELAB color values².

			L*	a*	b*	Chroma	Hue angle
Pre Package	Fresh	MAP	38.78 ^a	13.79 ^{defg}	9.71 ^{bc}	16.89 ^{cde}	34.95 ^{bc}
	Domestic	PVC	38.73 ^a	13.67 ^{cfg}	9.68 ^{bc}	16.79 ^{cdef}	35.52 ^{bc}
		VAC	39.03 ^a	13.83 ^{cdef}	9.82 ^b	16.99 ^{cde}	35.52 ^{bc}
	Frozen	MAP	35.79 ^b	14.85 ^c	9.39 ^{bcd}	17.61 ^c	32.09 ^d
	Domestic	PVC	35.65 ^b	14.43 ^{cde}	8.96 ^{cde}	17.02 ^{cde}	32.09 ^{de}
		VAC	35.84 ^b	14.6 ^{cde}	9.33 ^{bcd}	17.38 ^{cd}	32.66 ^d
	Frozen	MAP	33.26 ^c	14.76 ^{cd}	8.35 ^{fe}	16.98 ^{cde}	29.22 ^{fg}
	Australian	PVC	32.95 ^c	14.12 ^{cdef}	7.93 ^f	16.21 ^{cd}	29.22 ^{fg}
		VAC	32.92 ^c	14.57 ^{cde}	8.2 ^{fe}	16.73 ^{cde}	29.22 ^{fg}
		S.E.M. ¹	0.1218	0.0684	0.057	0.0806	0.1318
Post Package	Fresh	MAP	39.53 ^a	<u>18.16^a</u>	<u>10.73^a</u>	<u>21.12^a</u>	<u>30.37^{ef}</u>
	Domestic	PVC	40.05 ^a	13.57 ^{efg}	<u>11.4^a</u>	17.76 ^c	<u>40.11^a</u>
		VAC	39.65 ^a	13.81 ^{defg}	9.56 ^{bc}	16.82 ^{cdef}	34.95 ^c
	Frozen	MAP	35.82 ^b	<u>17.36^{ab}</u>	9.36 ^{bcd}	<u>19.76^b</u>	<u>28.07^{gh}</u>
	Domestic	PVC	35.63 ^b	13.04 ^g	9.68 ^{bc}	16.28 ^{de^f}	<u>36.67^b</u>
		VAC	36.03 ^b	13.78 ^{defg}	9.57 ^{bc}	16.87 ^{cde}	<u>34.95^{bc}</u>
	Frozen	MAP	33.45 ^c	<u>17.03^b</u>	8.68 ^{fed}	<u>19.13^b</u>	<u>26.93^h</u>
	Australian	PVC	33.07 ^c	13.13 ^{f^g}	8.42 ^{fe}	15.62 ^f	<u>32.66^d</u>
		VAC	32.98 ^c	13.66 ^{efg}	8.05 ^f	15.88 ^{ef}	30.37 ^{ef}
		S.E.M. ¹	0.1259	0.0933	0.0615	0.0996	0.1662

¹Standard error is reported as the average for the combined 9 per pack treatments and the average for the combined 9 post package treatments

²L* = Lightness; a* = redness; b= yellowness; Hue angle = $\tan^{-1}(b^*/a^*)$, where lower values indicated more redness; Chroma = Saturation Index = $(a^{*2}+b^{*2})^{1/2}$.

^{a-h}Means within the same column lacking a common superscript letter differ (P<0.05)

Post package means that are underlined significantly differ from their prepackage correspondent value.

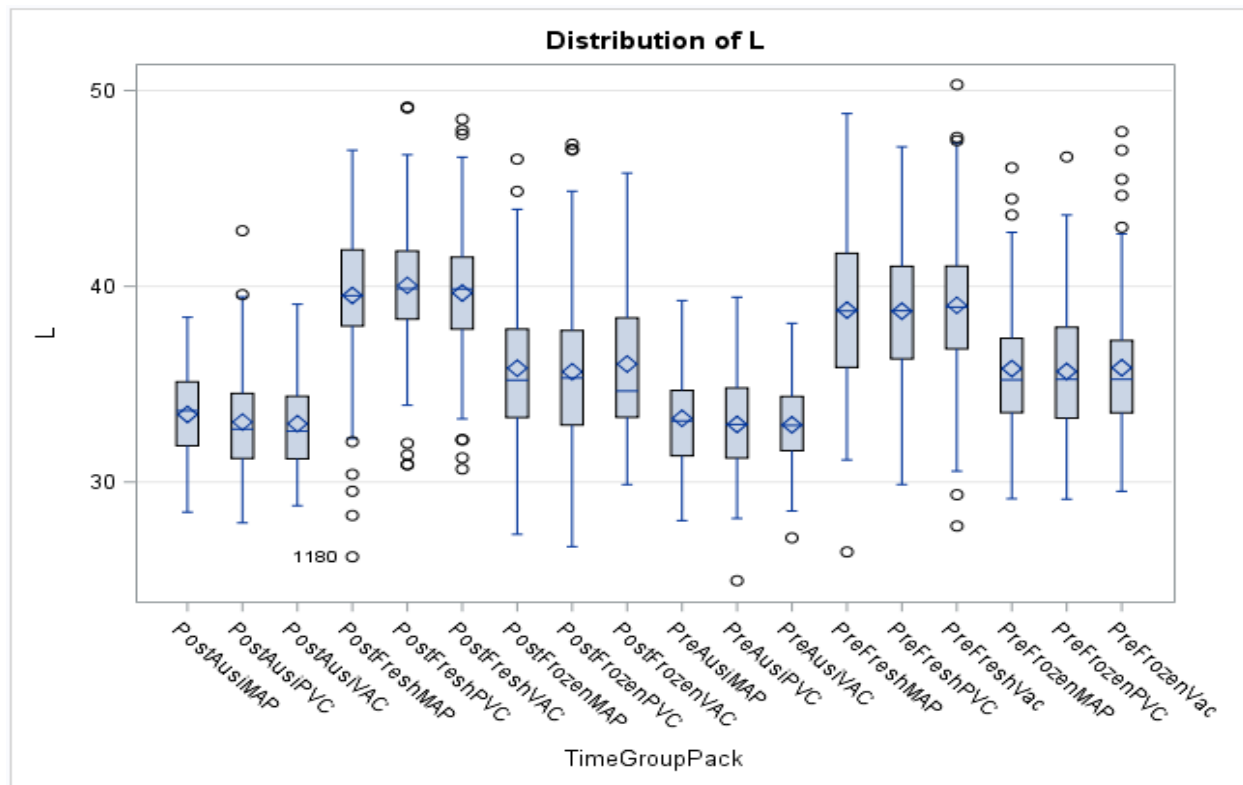


Figure 8. Box and Whisker plot of pre and post package group combination of L*

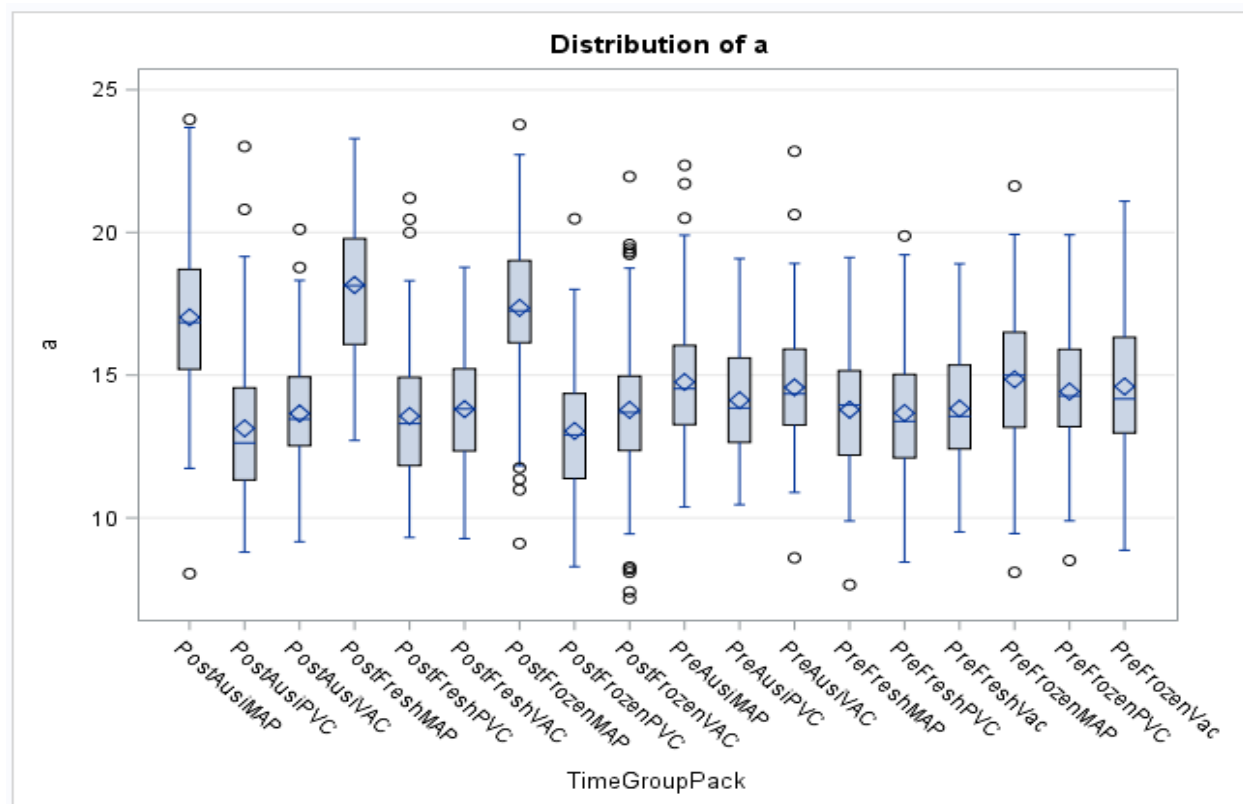


Figure 9. Box and Whisker plot of pre and post package group combination of a*

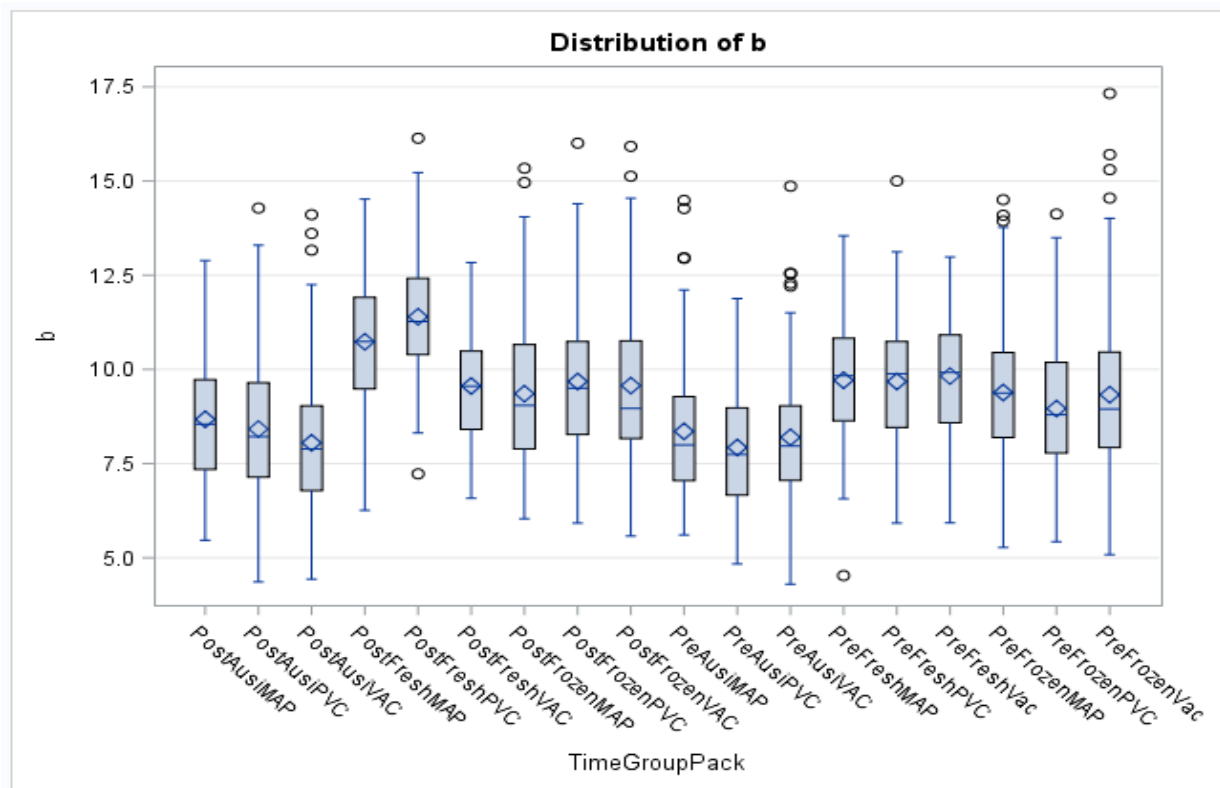


Figure 10. Box and Whisker plot of pre and post package group combination of b^*

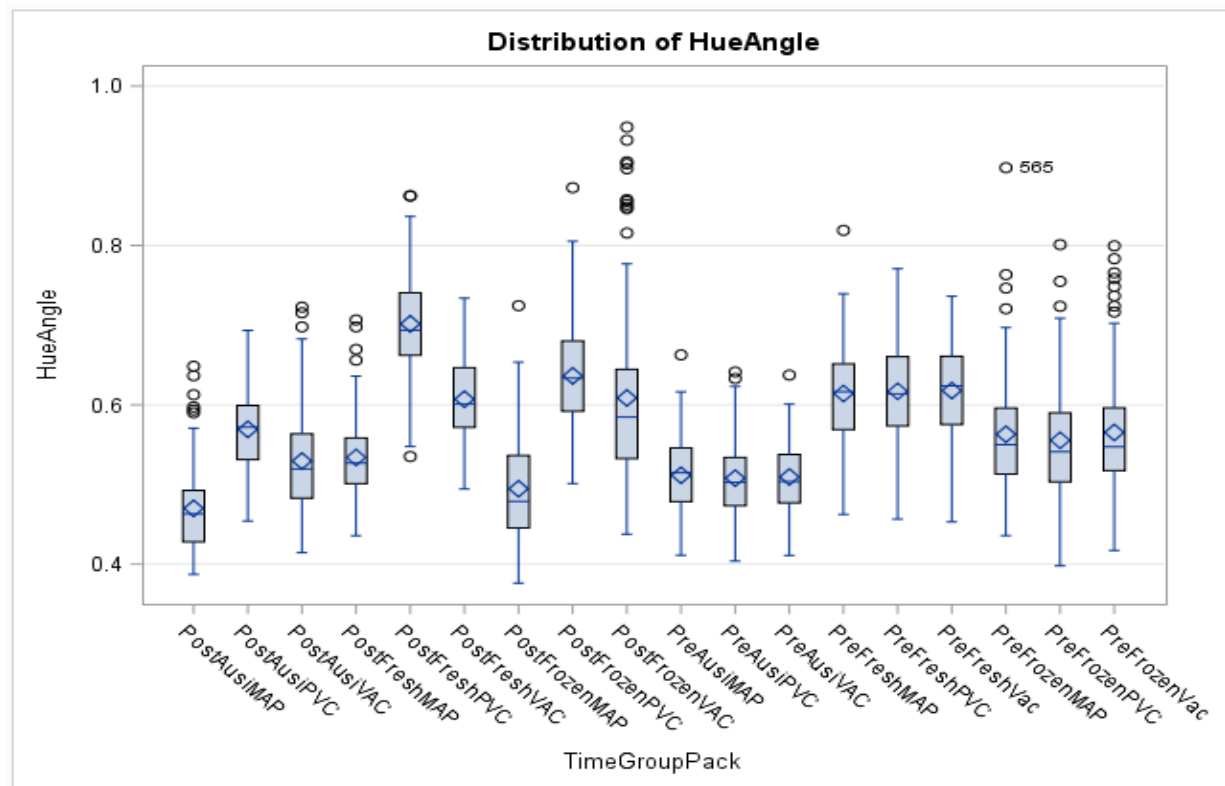


Figure 11. Box and Whisker plot of pre and post package group combination of hue angle

5.3.6 Loin and Rib Comparison

A comparison of rib and loin chops type as a main effect without consideration of storage group and packaging treatment effects on loss, color, and tenderness is in Table 10.

Table 10. Means and standard errors on differences between loin and rib chops on loss, color, and tenderness.

	Loin	Rib	S.E.M¹
<i>Loss</i>			
Drip Loss	4.01 ^a	3.56 ^b	0.0009
Cook Loss	15.59 ^a	14.11 ^b	0.0013
Total Loss	18.96 ^a	17.16 ^b	0.0015
<i>Pre Pack²</i>			
L*	35.34 ^b	36.43 ^a	0.1218
a*	13.98 ^b	14.61 ^a	0.0684
b*	8.70 ^b	9.39 ^a	0.0057
Chroma	16.51 ^b	17.41 ^a	0.0806
Hue angle	31.78 ^b	32.67 ^a	0.1318
<i>Post Pack²</i>			
L*	35.59 ^b	36.90 ^a	0.1259
a*	14.24 ^b	15.44 ^a	0.0933
b*	9.04 ^b	9.94 ^a	0.0615
Chroma	16.95 ^b	18.44 ^a	0.0996
Hue angle	32.61 ^a	32.97 ^a	0.1662
<i>Tenderness</i>			
WB	4286 ^a	3382 ^b	54.2069

¹Standard error is reported as the average for the combined 3 per pack treatments and the average for the combined 3 post package treatments

²L* = Lightness; a* = redness; b=yellowness; Hue angle = $\tan^{-1}(b^*/a^*)$, where lower values indicated more redness; Chroma = Saturation Index = $(a^{*2}+b^{*2})^{1/2}$.

^{ab}Means within the same row lacking a common superscript letter differ (P<0.05).

A surprising find of the study were the differences found when comparing loin and rib chops. Loin chops had a higher (P<0.05) percentage of drip loss, cook loss and total loss than did

rib chops. Rib chops had higher ($P<0.05$) values for L^* , a^* , b^* , and chroma for both pre and post package values than loin chops. Hue angle for rib chops was higher ($P<0.05$) prepackage than loin chops, but did not differ ($P>0.05$) post package. Loin chops were also less tender, having a higher ($P<0.05$) shear force value than rib chops. These tenderness differences due to location of loin or rib would be in line with research done on beef *Longissimus* steaks, which found similar results (Wheeler, Shackelford and Koohmaraie, 2007; Rhee et al., 2004).

5.4 Conclusion

It was concluded that freezing and thawing of goat carcasses will increase drip loss in packages during simulated display, and chops will have a greater cook loss even though chops were removed from the carcasses after freezing and carcass thaw loss had occurred. Freezing also led to less desirable color values, resulting in less desirable characteristics than fresh domestic goat meat. Some of the losses in desirable color such as a^* (redness) can be overcome through MAP packaging with 0.5% CO, while other values such as L^* seem to not be affected by packaging, but are dependent on freezing treatment.

Vacuum packaging of goat chops increased drip loss compared to other treatments, and PVC overwrapping had the least desirable color traits compared to other treatments and prepackage values. Packaging had no effect on tenderness values of chops. Freezing treatment greatly affected tenderness, however, as fresh domestic had higher shear force values than frozen domestic, and frozen domestic had higher values than frozen Australian.

Loin chops had greater drip and cook loss than rib chops. This is possibly due to different bone, fat, and muscle ratios, or due to a difference in water holding capacity of the *Longissimus dorsi* based on location. Further research would be needed for a determination to be

made. Rib chops were found to have more desirable color both pre and post package than loin chops.

Rib chops also had lower tenderness shear force values when compared to loin chops, which is likely due to the difference in location and the way that the animal uses the particular muscle.

CHAPTER 6: CONCLUSIONS

6.1 Summary

Imported frozen goat meat comprises over half of the documented goat meat available in the United States. There is little scientific literature that discusses the effects of freezing on goat carcasses and the quality of goat meat, especially when compared to fresh goat meat.

The objective of this research was to determine differences in carcass evaluation, yield and meat quality from representative fresh domestic, frozen domestic and frozen imported Australian goat carcass sides (n=30 from each source).

To achieve a comprehensive look at the differences among these groups, this study was done in three separate experiments. The experiments were conducted with two replications of fresh domestic goat sides and frozen domestic goat sides from goats from the United States and imported frozen Australian goat carcasses. The experiments evaluated goat carcass traits and meat yields, differences in goat leg properties, and comparison of loin and rib chops in three different packaging treatments from fresh and frozen domestic and imported frozen goat carcasses.

There are obvious confounding factors that occurred between the Australian goat carcasses and the domestic carcasses, but this study was designed to determine if Australian carcass traits would be more closely related to those of the frozen domestic carcasses than those of the fresh domestic carcasses. This was the overall trend seen through the experiments, which led to the assumption that many of the quality characteristics that were observed in the Australian goat carcasses were due to freezing and frozen storage rather than other production practices that were not able to be controlled.

6.2 Findings

Data from this study suggested that, when comparing carcass traits, Australian goat carcasses were leaner than the market ready domestic counterparts, while their conformation scores and flank color did not differ. Furthermore, freezing carcass sides caused a significant decrease in carcass side weight after thawing. It was also observed that freezing and thawing caused different primal cuts to change as a percent ratio when compared to their side weight or to the cold carcass weight.

When comparing goat legs from the fresh domestic, frozen domestic and frozen Australian treatments, it was concluded that freezing and thawing of goat legs increased drip and cook losses and negatively affected desirable CIELAB color values, resulting in less desirable characteristics of frozen and thawed meat than fresh domestic goat meat.

In the loin and rib study, where loin and rib chops from fresh domestic, frozen domestic and frozen Australian carcasses were packaged and displayed in different packaging types, it was concluded that freezing and thawing of goat carcasses increased drip losses in package and chops had a greater cook loss, even though chops were removed from the carcass after freezing and carcass thaw loss had occurred. Freezing also led to less desirable color values, resulting in overall less desirable characteristics than fresh domestic goat meat. Some of these losses in desirable color such as a^* (redness) might be overcome through MAP packaging with 0.5% CO₂, while other values such as L^* seemed not to be affected by packaging, but fully dependent on freezing treatment.

Vacuum packaging of goat chops increased drip loss compared to other treatments, and chops in PVC overwrap packaging had the least desirable color traits compared to other treatments and prepackage values. Surprisingly, packaging had no effect on tenderness values of

chops. Freezing treatment greatly affected tenderness, however, as fresh domestic chops had higher shear force values than frozen domestic chops, and frozen domestic chops had higher values than frozen Australian chops.

Loin chops had greater drip and cook loss than rib chops while rib chops had more desirable color both pre and post package than loin chops.

Rib chops also had lower tenderness shear force values when compared to loin chops, which is likely due to the difference in location and the way that the animal uses the particular muscle.

Overall, when comparing representative young goats from fresh domestic, frozen domestic and frozen Australian sources, a noticeable decrease in the ability of the frozen meat to retain water across all tests was observed. This will probably be detrimental to businesses selling thawed goat carcasses or cuts, as the drip loss will reduce the total meat weight and meat is generally bought and sold by weight.

There was also a decrease in the desirable red color (hue), the saturation of color (chroma), and the value (lightness) associated with meat of cuts that came from frozen and thawed carcasses. Goat meat had lower shear force with freezing and thawing, but it is important to note that this was only a measurement of mechanical tenderness. A consumer panel might perceive the tenderness of the chops differently because there are other factors, such as juiciness, that affect the perception of tenderness.

6.3 Implications

There is a need for further research in many areas addressed by this paper. Testing the effects of different rates of freezing and effects of frozen storage duration on goat meat would be beneficial to producers, especially those from foreign sources that require freezing to optimize

their production practices while ensuring the highest possible quality. While previous research has been done in goat packaging, testing the effects over different types of MAP packaging at different display durations should be a priority, as MAP, particularly types with carbon monoxide, continues to comprise a greater percentage of packages in retail meat markets.

Lastly, there were obvious confounding effects between the domestic and Australian samples that were unavoidable due to the resources available to this study. To remedy this, it is recommended that a future study involve sampling representative fresh feral goat carcass sides in Australia and shipping frozen sides to America under standard shipping conditions would allow accounting for all variation that may occur due to production and processing practices.

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VITA

Jeffrey Cole Denis Gregorie was raised in Mangham, Louisiana by his loving grandparents Robert and Faye Bell. He spent much of his youth on the family cotton farm and in the woods hunting. It was there at an early age that he developed a love for agriculture and an early familiarity with basic meat science through the harvest and processing of the game by him and his family. He graduated from Mangham High School in 2006 and enrolled at Louisiana State University and A&M College, receiving a bachelor's degree in animal science in 2010. In his time at LSU, he became a proud member of ALPHA GAMMA RHO: Alpha Epsilon chapter. It was through his fraternity that he made many lifelong friends and met the love of his life, and future wife. Shortly after graduation, he began work as a research associate in the animal science department at the LSU Meat Lab. This allowed him an opportunity to pursue a secondary degree in Meat Science.

Cole is currently a research associate at the LSU AgCenter Sweet Potato Research Station in Chase, Louisiana. After graduation, he plans to hopefully get back to a normal work schedule, spend more time with his precious baby girl, Lisa Bell Gregorie, and wife, Elizabeth Gregorie, and prepare for duck season. There are currently no plans for further education as of now, but the future is unwritten.

“There are those that look at things the way they are, and ask why? I dream of things that never were, and ask why not?”

-Robert Kennedy